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OF

SIR HUMPHRY DAVY, BART.
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EDITED BY HIS BROTHER,
JOHN DAVY, M.D. F.R.S.

11 3 //

VOL. III.

RESEARCHES, CHIEFLY CONCERNING NITROUS
OXIDE.

LONDON:
SMITH, ELDER AND CO. CORNHILL.
1839.

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LONDON:
PRINTED BY STEWART AND MURRAY, OLD BAILEY.

MERCURIAL AIR-HOLDER and BREATHING MACHINE.

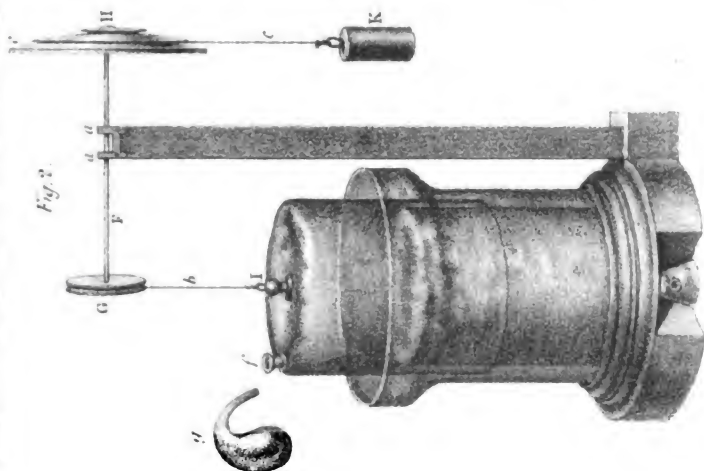


Fig. 3.

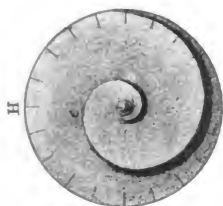
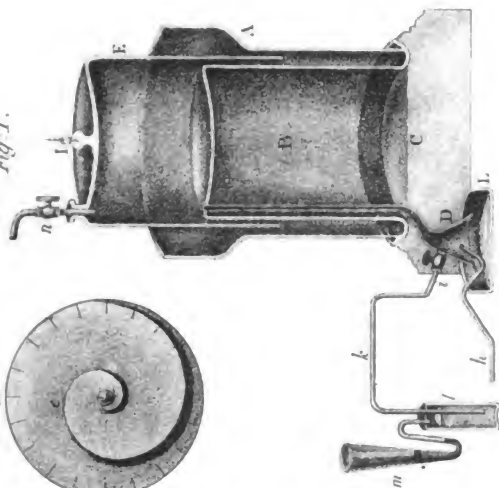


Fig. 1.



RESEARCHES,

CHEMICAL AND PHILOSOPHICAL,

CHIEFLY CONCERNING

NITROUS OXIDE, OR DEPHLOGISTICATED NITROUS AIR,
AND ITS RESPIRATION.

BY SIR HUMPHRY DAVY, BART.

LONDON:
SMITH, ELDER AND CO. CORNHILL.
1839.

Chem 78.1



[THIS volume comprises the author's Researches on Nitrous Oxide and the combinations of oxygen and azote, and on the respiration of nitrous oxide and other gases, first published in 8vo. in the summer of 1800.

In one of his note-books kept at that time, in a rough draught of a preface, referring to these Researches, he says, "These experiments have been made since April, 1799, the period when I first breathed nitrous oxide. Ten months of incessant labour were employed in making them, three months in detailing them."

Dr. Thomson, in his History of Chemistry, observes, "This work gave him at once a high reputation as a chemist, and was really a wonderful performance, when the circumstances under which it was produced are taken into consideration."

It was written throughout on the strictly inductive plan, with a total rejection of that almost abstract speculation, or hasty generalization of which in the preface, he says, (alluding to his Essays on Heat and Light), early experience had taught him the folly.

In every way, the work may be considered characteristic of his rapidly matured mind; and equally characteristic were his aspirations when he had completed it: in an unpublished dedication of the "Researches" to Dr. Beddoes, he begs him to receive them "as pledges of more important labours."]

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RESEARCHES

CHEMICAL AND PHILOSOPHICAL.

INTRODUCTION.

IN consequence of the discovery of the respirability and extraordinary effects of nitrous oxide, or the dephlogisticated nitrous gas of Dr. Priestley, made in April, 1799, in a manner to be particularly described hereafter,* I was induced to carry on the following investigation concerning its composition, properties, combinations, and mode of operation on living beings.

In the course of this investigation, I have met with many difficulties; some arising from the novel and obscure nature of the subject, and others from a want of coincidence in the observations of different experimentalists on the properties and mode of production of the gas. By extending my researches to the different substances connected with nitrous oxide; nitrous acid, nitrous gas and ammonia; and by multiplying the comparisons of facts, I have succeeded in removing the

* A short account of this discovery has been given in Dr. Beddoes's Notice of some Observations made at the Pneumatic Institution, and in Phil. Journal for May and December, 1799.—[Vide note, vol. ii. p. 61.]

greater number of those difficulties, and have been enabled to give a tolerably clear history of the combinations of oxygen and nitrogen.

By employing both analysis and synthesis whenever these methods were equally applicable, and comparing experiments made under different circumstances, I have endeavoured to guard against sources of error; but I cannot flatter myself that I have altogether avoided them. The physical sciences are almost wholly dependent on the minute observation and comparison of properties of things not immediately obvious to the senses; and from the difficulty of discovering every possible mode of examination, and from the modification of perceptions by the state of feeling, it appears nearly impossible that all the relations of a series of phenomena can be discovered by a single investigation, particularly when these relations are complicated, and many of the agents unknown. Fortunately for the active and progressive nature of the human mind, even experimental research is only a method of approximation to truth.

In the arrangement of facts, I have been guided as much as possible by obvious and simple analogies only. Hence I have seldom entered into theoretical discussions, particularly concerning light, heat, and other agents, which are known only by isolated effects.

Early experience has taught me the folly of hasty generalisation. We are ignorant of the laws of corpuscular motion; and an immense mass of minute observations concerning the more complicated chemical changes must be collected, probably before we shall be able to ascertain even whether we are capable of discovering them. Chemistry in its present state, is simply a partial history of phenomena, consisting of many series more or less extensive of accurately connected facts.

With the most important of these series, the arrangement of the combinations of oxygen or the antiphlogistic theory discovered by Lavoisier, the chemical details in this work are capable of being connected.

In the present state of science, it will be unnecessary to enter into discussions concerning the importance of investigations relating to the properties of physiological agents, and the changes effected in them during their operation. By means of such investigations, we arrive nearer towards that point from which we shall be able to view what is within the reach of discovery, and what must for ever remain unknown to us, in the phenomena of organic life. They are of immediate utility, by enabling us to extend our analogies so as to investigate the properties of untried substances, with greater accuracy and probability of success.

The First Research in this work chiefly relates to the production of nitrous oxide and the analysis of nitrous gas and nitrous acid. In this there is little that can be properly called mine; and if by repeating the experiments of other chemists, I have sometimes been able to make more minute observations concerning phenomena, and to draw different conclusions, it is wholly owing to the use I have made of the instruments of investigation discovered by the illustrious fathers of chemical philosophy,* and so successfully applied by them to the discovery of truth.

In the Second Research the combinations and composition of nitrous oxide are investigated, and an account given of its decomposition by most of the combustible bodies.

The Third Research contains observations on the

* Cavendish, Priestley, Black, Lavoisier, Scheele, Kirwan, Guyton, Berthollett, &c.

action of nitrous oxide upon animals, and an investigation of the changes effected in it by respiration.

In the Fourth Research the history of the respirability and extraordinary effects of nitrous oxide is given, with details of experiments on its powers made by different individuals.

I cannot close this introduction, without acknowledging my obligations to Dr. Beddoes. In the conception of many of the following experiments, I have been aided by his conversation and advice. They were executed in an Institution which owes its existence to his benevolent and philosophic exertions.

DOWRY SQUARE, HOTWELLS, BRISTOL,
June 25th, 1800.

RESEARCH I.

INTO THE PRODUCTION AND ANALYSIS OF NITROUS
OXIDE, AND THE AERIFORM FLUIDS RELATED TO IT.

DIVISION I.

EXPERIMENTS AND OBSERVATIONS ON THE COMPOSITION
OF NITRIC ACID, AND ON ITS COMBINATIONS WITH
WATER AND NITROUS GAS.

I. THOUGH since the commencement of Pneumatic Chemistry, no substance has been more the subject of experiment than nitrous acid; yet still the greatest uncertainty exists with regard to the quantities of the principles entering into its composition.

In comparing the experiments of the illustrious Cavendish on the synthesis of nitrous acid, with those of Lavoisier on the decomposition of nitre by charcoal, we find a much greater difference in the results than can be accounted for by supposing the acid formed, and that decomposed, of different degrees of oxygenation.

In the most accurate experiment of Cavendish, when the nitrous acid appeared to be in a state of deoxygenation, 1 of nitrogen combined with about 2.346 of oxygen.* In an earlier experiment, when the acid was probably fully oxygenated, the nitrogen employed was to the oxygen nearly as 1 to 2.92.†

Lavoisier, from his experiments on the decomposition

* Phil. Trans. v. 78. p. 270.

† Phil. Trans. v. 75. p. 381.

of nitre, and combination of nitrous gas and oxygen, concludes that the perfectly oxygenated, or what he calls nitric acid, is composed of nearly 1 nitrogen, with 3.9 of oxygen; and the acid in the last state of deoxygenation, or nitrous acid, of about 2 oxygen with 1 nitrogen.*

Great as the difference is between the estimations of these philosophers, we find differences still greater in the accounts of the quantities of nitrous gas necessary to saturate a given quantity of oxygen, as laid down by very accurate experimentalists. On the one hand, Priestley found 1 of oxygen condensed by 2 of nitrous gas, and Lavoisier by $1\frac{1}{8}$. On the other, Ingenhouz, Scherer, and De la Metherie, state the quantity necessary to be from 3 to 5.† Humboldt, who has lately investigated Eudiometry with great ingenuity, considers the mean quantity of nitrous gas necessary to saturate 1 of oxygen, as about 2.55.‡

II. To reconcile these different results is impossible, and the immediate connection of the subject with the production of nitrous oxide, as well as its general importance, obliged me to search for means of accurately determining the composition of nitrous acid in its different degrees of oxygenation.

The first desideratum was to ascertain the nature and composition of a fluid acid, which by being deprived of, or combined with nitrous gas, might become a standard of comparison for all other acids.

To obtain this acid I should have preferred the imme-

* Elem. Kerr's Trans. p. 76 and 216, and Mem. des Sav. Etrang. tom. 7. p. 629.

† Ingenhouz sur les Vegetaux, p. 205. De la Metherie, Essai sur differens Airs, p. 252.

‡ Annales de Chimie, tom. 28. p. 168.

diate combination of oxygen and nitrogen over water by the electric spark, had it been possible to obtain in this way by a common apparatus sufficient for extensive examination; but on carefully perusing the laborious experiments of Cavendish, I gave up all thoughts of attempting it.

My first experiments were made on the decomposition of nitre, formed from a known quantity of pale nitrous acid of known specific gravity, by phosphorus, tin, and charcoal: but in those processes, unascertainable quantities of nitrous acid, with excess of nitrous gas, always escaped undecomposed, and from the noncoincidence of results, where different quantities of combustible substances were employed, I had reasons for believing that water was generally decomposed.

Before these experiments were attempted, I had analyzed nitrous gas and nitrous oxide, in a manner to be particularly described hereafter; so that a knowledge of the quantities of nitrous gas and oxygen entering into the composition of any acid, enabled me to determine the proportions of nitrogen and oxygen it contained. In consequence of which I attempted to combine together oxygen and nitrous gas, in such a manner as to absorb the nitrous acid formed by water, in an apparatus by which the quantities of the gases employed, and the increase of weight of the water, might be ascertained; but this process likewise failed. It was impossible to procure the gases perfectly free from nitrogen, and during their combination, this nitrogen, made to pass into a pneumatic apparatus communicating with a vessel containing the water, carried over with it much nitrous acid vapour, of different composition from the acid absorbed.

After many unsuccessful trials, Dr. Priestley's experi-

ments on nitrous vapour* induced me to suppose that oxygen and nitrous gas, made to combine out of the contact of bodies having affinity for oxygen, would remain permanently aëriform, and on throwing them separately into an exhausted glass balloon, I found that this was actually the case; increase of temperature was produced, and orange coloured nitrous acid gas formed, which after remaining for many days in the globe, at a temperature below 56° , did not in the slightest degree condense.

This fact afforded me the means not only of forming a standard acid, but likewise of ascertaining the specific gravity of nitrous acid in its aëriform state.

III. Previous to the experiment, for the purpose of correcting incidental errors, I was induced to ascertain the specific gravity of the gases employed, particularly as I was unacquainted with any process by which the weight of nitrous gas had been accurately determined. Mr. Kirwan's estimation, which is generally adopted, being founded upon the comparison of the loss of weight of a solution of copper in dilute nitrous acid, with the quantity of gas produced.†

The instruments that I made use of for containing and measuring my gases, were two mercurial air-holders graduated to the cubic inch of Everard, and furnished with stop cocks.‡

* Experiments and Observations, vol. iii. last edition, p. 105, &c.

† When copper is dissolved in dilute nitrous acid, certain quantities of nitrogen are generally produced, likewise the nitrous gas carries off in solution some nitrous acid.

‡ This air-holder, considered as a pneumatic instrument, is of greater importance, and capable of a more extensive application than any other. It was invented by Mr. W. Clayfield, and in its form is analogous to Mr. Watt's hydraulic bellows, consisting of a glass bell playing under the pressure of the atmosphere, in a space between two cylinders filled with mercury. A particular account of it will be given in the Appendix.

They were weighed in a glass globe, of the capacity of 108 cubic inches, which with the small glass stop-cock affixed to it, was equal, when filled with atmospheric air, to 1755 grains. The balance that I employed, when loaded with a pound, turned with less than one-eighth of a grain.

Into a mercurial air-holder, of the capacity of 200 cubic inches, 160 cubic inches of nitrous gas were thrown from a solution of mercury in nitrous acid.

70 measures of this were agitated for some minutes in a solution of sulphate of iron,* till the diminution was complete. The nitrogen remaining hardly filled a measure; and if we suppose with Humboldt† that a very small portion of it was absorbed with the nitrous gas, the whole quantity it contained may be estimated at 0.0142, or $\frac{1}{70}$.

75 cubic inches received from the air-holder into an exhausted balloon, increased it in weight 25.5 grains; thermometer being 56°, and barometer 30.9. And allowing for the small quantity of nitrogen in the gas, 100 cubic inches of it will weigh 34.3 grains.

130 cubic inches of oxygen were procured from oxide of manganese and sulphuric acid, by heat, and received in another mercurial air-holder.

10 measures of it, mingled with 26 of the nitrous gas, gave, after the residuum was exposed to solution of sulphate of iron, rather more than one measure. Hence we may conclude that it contained about 0.1 nitrogen.

60 cubic inches of it weighed 20.75 grains; and accounting for the nitrogen contained in these, 100 grains of pure oxygen will weigh 35.09 grains.

* This absorption will be hereafter particularly treated of.

† *Annales de Chimie.* tom. 18. p. 139.

Atmospherical air was decomposed by nitrous gas in excess; and the residuum washed with solution of sulphate of iron till the nitrogen remained pure; 87 cubic inches of it weighed 26·5 grains, thermometer being 48°, barometer 30·1; 100 will consequently weigh 30·45.

90 cubic inches of the air of the laboratory not deprived of its carbonic acid, weighed 28·75 grains; thermometer 53, barometer 30: 100 cubic inches will consequently weigh 31·9.* Sixteen measures of this air, with 16 nitrous gas, of known composition, diminished to 19.† Hence it contained about 26 oxygen.‡

In comparing my results with those of Lavoisier and Kirwan, the estimation of the weights of nitrogen and oxygen is very little different, the corrections for temperature and pressure being made from that of those celebrated philosophers. The first makes oxygen to weigh § 34·21 and nitrogen 30·064 per cent.; and the last, oxygen 34,|| and nitrogen 30·5.

The specific gravity of nitrous gas, according to Kirwan, is to that of common air as 1194 to 1000. Hence it should weigh about 37 grains per cent. This difference from my estimation is not nearly so great as I expected to have found it.¶

* A table of the specific gravities of these gases, and other gases, hereafter to be mentioned, reduced to a barometrical and thermometrical standard, will be given in the Appendix.

† Forty measures, exposed to solution of potash, gave an absorption of not quite a quarter of a measure: hence it contained an inconsiderable quantity of carbonic acid.

‡ [Vide his later and more accurate estimate, Vol. II. p. 231.]

§ *Traité Elementaire.*

|| *Essai sur le Phlogistique*, p. 30.

¶ The diminution of the specific gravity of the gas from the quantity of nitrogen evolved in his experiment, probably destroyed, in some measure, the source of error from the nitrous acid carried over.

IV.* The thermometer in the laboratory standing at 55° , and the barometer at 30.1, I now proceeded to my experiment. The oxygen that I employed was of the same composition as that which I had previously weighed. The nitrous gas contained .0166 nitrogen.

For the purpose of combining the gases, a glass balloon was procured, of the capacity of 148 cubic inches, with a glass stop-cock adapted to it, having its upper orifice tubulated and graduated for the purpose of containing and measuring a fluid. The whole weight of this globe and its appendages, when filled with common air, was 2066.5 grains.

It was partially exhausted by the air-pump, and lost in weight just 32 grains. From whence we may conclude that about 15 grains of air remained in it.

In this state of exhaustion it was immediately cemented to the stop-cock of the mercurial air-holder, and the communication being made with great caution, 82 cubic inches of nitrous gas rushed into the globe, on the outside of which a slight increase of temperature was perceived, while the gases on the inside appeared of a deep orange.

Before the common temperature was restored, the communication was stopped, and the globe removed. The increase of weight was 29.25 grains; whence it appeared that 1.14 grains of common air, part of which had been contained in the stop-cocks, had entered with the nitrous gas.

Whilst it was cooling, from the accidental loosening of the stopper of the cock, three grains more of common air entered. †

* Experiment I.

† That no greater contraction took place, depended on the solution of the nitrous acid formed in the nitrous gas; a phenomenon to be explained hereafter.

The communication was now made between the globe and the mercurial air-holder containing oxygen. 64 cubic inches were slowly pressed in, when the outside of the globe became warmer, and the colour on the inside changed to a very dark orange. As it cooled, 6 cubic inches more slowly entered; but no new increase of temperature, or change of colour took place.

The globe being now completely cold, was stopped, removed, and weighed; it had gained 24·5 grains, from whence it appears that 0·4 grains of common air contained in the stop-cocks, had entered with the oxygen.*

To absorb the nitrous acid gas, 41 grains of water were introduced by the tube of the stop-cock, which though closed as rapidly as possible, must have suffered nearly ·5 grain of air to enter at the same time, as the increase of weight was 41·5 grains. The dark orange of the globe diminished rapidly; it became warm at the bottom, and moist on the sides. After a few minutes, the colour had almost wholly disappeared.

To ascertain the quantity of aëriform fluid absorbed, the globe was again attached to the mercurial air apparatus, containing 140 cubic inches of common air. When the communication was made, 51 cubic inches rushed in, and it gained in weight 16·5 grains.

A quantity of fluid equal to 54 grains was now taken out of the globe. On examination it proved to be slightly tinged with green, and occupied a space equal to that filled by 41·5 grains of water. Its specific gravity was consequently 1·301.

To ascertain if any unabsorbed aëriform nitrous acid

* I judged it expedient always to ascertain the quantity of air in the stop-cocks by weight, as it was impossible to join them so as to have always an equal capacity. The upper tubes of the two stop-cocks not joined, contained nearly an inch and half.

remained in the globe, 13 grains of solution of ammonia were introduced in the same manner as the water, and after some minutes, when the white vapour had condensed, the communication was again made with the mercurial air-holder containing common air. A minute quantity entered, which could not be estimated at more than three-fourths of an inch, and the globe was increased in weight about 13·25 grains.*

Common air was now thrown into the globe till the residual gases of the experiment were judged to be displaced; it weighed 2106·5 grains, that is, 40 grains more than it had weighed when filled with common air before the experiment.†

And if from those 40 grains we take 13 for the solution of ammonia introduced, the remainder, 27, will be the quantity of solution of nitrous acid in water remaining in the globe, which added to 54, equals 81 grains, the whole quantity formed; but if from this be taken 41 grains, the quantity of water, the remainder 40 grains, will be the quantity of nitrous acid gas absorbed in the solution.

To find the absolute quantity of nitrous acid formed, we must find the specific gravity of that absorbed; but

* That is, by the solution of ammonia, and air.

† The following is an account of the increase and diminution of weight of the globe, as it was noted in the journal.

Globe filled with common air	2066·5 grains
After exhaustion	2034·5
After introduction of nitrous gas, 82 cubic inches	2064·25
After the accidental admission of common air	2067·25
After the admission of oxygen	2091·75
" " 41 grains of water	2133·25
" " 51 cubic inches of air	2149·75
Taken out 54 grains of solution	2095·75
Introduced 13 grains of ammoniacal solution	2109·25
After introduction of common air	2106·5

as during, and after its absorption, 17 grains of air, equal to 53·2 cubic inches entered, it evidently filled such a space. 53·2 cubic inches of it consequently weigh 40 grains, and 100 cubic inches 75·17 grains. Then ·75 cubic inches weigh ·56 grains, and this added to 40, makes 40·56 grains, equal to 53·95 cubic inches, the whole quantity of aëriform nitrous acid produced.

But the quantity of nitrous gas entering into this, allowing for the nitrogen it contained, is 27·6 grains, equal to about 80·5 cubic inches; and the oxygen is $40·56 - 27·6 =$ to 12·96 grains, or 36·9 cubic inches.

V. There could exist in this experiment no circumstance connected with inaccuracy, except the impossibility of very minutely determining the quantities of common air which entered with the gases from the stop-cocks. But if errors have arisen from this source, they must be very inconsiderable; as will appear from a calculation of the specific gravity of the nitrous acid gas, founded on the volume of the gases that entered the globe.

The air that remained in the globe after		
exhaustion was 15 grains	=	47* cub. in.
The nitrous gas introduced was	-	82
Common air	- - - - -	13
Oxygen	- - - - -	70
Common air	- - - - -	1
Whole quantity of air thrown into the		
globe	- - - - -	213
From which subtract its capacity	-	148
The remainder is	- - -	65

* Decimals are omitted, because the excess of the two first numbers is exactly corrected by the deficiency of the last.

And this remainder taken from 80·5 nitrous gas + 36·9 oxygen, leaves 52·4 cubic inches, which is the space occupied by the nitrous acid gas, and which differs from 53·95 only by 1·55 cubic inches.

I ought to have observed, that before this conclusive experiment, two similar ones had been made. In comparing the results of one of them, performed with the assistance of my friend, Mr. Joseph Priestley, Dr. Priestley's eldest son, and chiefly detailed by him in the journal, I find a coincidence greater than could be even well expected, where the processes are so complex. According to that experiment, 41·5 grains of nitrous acid gas fill a space equal to 53 cubic inches, and are composed of nearly 29 nitrous gas, and 12·5 oxygen.

We may then conclude, First, that 100 cubic inches of nitrous acid, such as exists in the * aëriform state saturated with oxygen, at temperature 55°, and atmospheric pressure 30·1, weigh 75·17 grains.

Secondly, that 100 grains of it are composed of 68·06 nitrous gas, and 31·94 oxygen. Or assuming what will be hereafter proved, that 100 parts of nitrous gas consist of 55·95 oxygen, and 44·05 nitrogen, of 29·9 nitrogen, and 70·1 oxygen; or taking away decimals, of 30 of the one to 70 of the other.

Thirdly, that 100 grains of pale green solution of nitrous acid in water, of specific gravity 1·301, are composed of 50·62 water, and 49·38 acid of the above composition.

VI. Having thus ascertained the composition of a standard acid, my next object was to obtain it in a more condensed state, as it was otherwise impossible to saturate it to its full extent with nitrous gas. But this I

* As is evident from the superabundant quantity of oxygen thrown into the globe.

could effect in no other way than by comparing mixtures of known quantities of water, and acids of different specific gravities and colours, with the acid of 1·301.

For the purpose of combining my acids with water, I made use of a cylinder about 8 inches long, and ·3 inches in diameter, accurately graduated to grain measures, and furnished with a very tight stopper.

The concentrated acid was first slowly poured into it, and the water gradually added till the required specific gravity was produced;* the cylinder being closed and agitated after each addition, so as to produce combination without any liberation of elastic fluid.

After making a number of experiments with acids of different colours in this advantageous way, I at length found that 90 grains of a deep yellow acid, of specific gravity 1·5, became, when mingled at 40° with 77·5 grains of water, of specific gravity 1·302, and of a light green tinge, as nearly as possible resembling that of the standard acid.

Supposing, then, that these acids contain nearly the same relative proportions of oxygen and nitrogen, 100 grains of the deep yellow acid of 1·5, are composed of 91·9 grains true nitrous acid,† and 8·1 grains of water.

To ascertain the difference between the composition of this acid, and that of the pale, or nitric acid, of the same specific gravity, I inserted 150 grains of it into a small cylindrical matrrass of the capacity of ·5 cubic

* The weight of the acid poured into the cylinder being known, its specific gravity was known from the space it occupied in the phial. The weight of water being likewise known, the specific gravity of the solution, when the common temperature was produced, was given by the condensation.

† That is, such as it exists in the aëriform state at 55°. From the strong affinity of nitrous acid for water, we may suppose that this acid gas contains a larger proportion of it than the other gases.

inches, accurately graduated to grain measures, and connected by a curved tube with the water apparatus. After heat had been applied to the bottom of the mat-rass for a few minutes, the colour of the fluid gradually changed to a deep red, whilst the globules of gas formed at the bottom of the acid, were almost wholly absorbed in passing through it. In a short time deep red vapour began to fill the tube, and being condensed by the water in the apparatus, was converted into a bright green fluid, at the same time that minute globules of gas were given out. As the heat applied became more intense, a very singular phenomenon presented itself; the condensed vapour, increased in quantity, at length filled the curvature of the tube, and when expelled, formed itself into dark green spherules, which sunk to the bottom of the water, rested for a moment, and then resolved themselves into nitrous gas.*

When the acid was become completely pale, it was suffered to cool, and weighed. It had lost near 15 grains, and was of specific gravity 1.491. Two cubic inches and a quarter of nitrous gas only were collected.

From this experiment evidently no conclusions could be drawn, as the nitrous gas had carried over with it much nitrous acid (in the form of what Dr. Priestley calls nitrous vapour) and was partially dissolved with it in the water.†

To ascertain, then, the difference between the pale and yellow acids, I was obliged to make use of synthesis, compared with analysis, carried on in a different mode, by means of the following apparatus.

VII. To the stop-cock of the upper cylinder of the mercurial air-holder, a capillary tube was adapted, bent

* This appearance will be explained hereafter.

† This phenomenon will be particularly explained hereafter.

so as to be capable of introduction into an orifice in the stopper of a graduated phial similar to that employed for mingling acids with water, and sufficiently long to reach the bottom. With another orifice in the stopper of the phial was connected a similar tube curved, for the purpose of containing a fluid, and of increased diameter at the extremity.*

Fifty cubic inches of pure nitrous gas† were thrown into the mercurial apparatus. The graduated phial, containing 90 grains of nitric acid, of specific gravity 1.5, was placed on the top of the air-holding cylinder, and made to communicate with it by means of the stop-cock and first tube. Into the second tube a small quantity of solution of potash was placed. When all the junctures were carefully cemented, by pressing on the air-holder, the nitrous gas was slowly passed into the phial, and absorbed by the nitrous acid it contained; whilst the small quantities of nitrogen evolved, slowly drove forward the solution in the curved tube; from the height of which, as compared with that of the mercury in the conducting tube, the pressure on the air in the cylinder was known.

In proportion as the nitrous gas was absorbed, the phial became warm, and the acid changed colour; it first became straw-coloured, then pale yellow, and when about seven and a half cubic inches had been combined with it, bright yellow. It had gained in weight nearly three grains, and was become of specific gravity 1.496.

This experiment afforded me an approximation to

* The outline only of this apparatus is given here, as far as was necessary to make the experiment intelligible; a detailed account of it and of its general application, will be given in the Appendix.

† That is, from nitrous acid and mercury.

the real difference between nitric and yellow nitrous acid; and learning from it that nitric acid was diminished in specific gravity by combination with nitrous gas, I procured a pale acid of specific gravity 1.504.* After this acid had been combined in the same manner as before, with about 8 cubic inches of nitrous gas,† it became nearly of specific gravity 1.5, and had gained in weight about 3 grains.

Assuming the accuracy of this experiment as a foundation for calculation, I endeavoured in the same manner to ascertain the differences in the composition of the orange-coloured acids, and the acids containing still larger proportions of nitrous gas.

93 grains of the bright yellow acid of 1.5 became, when 6 cubic inches of gas had been passed through it, orange-coloured and fuming, whilst the undissolved gas increased in quantity so much as to render it impossible to confine it by the solution of potash. When 9 cubic inches had passed through, it became dark orange. It had gained in weight 2.75 grains, and was become of specific gravity 1.48 nearly. Hence it was evident that much nitrous gas had passed through it undissolved. 25 cubic inches more of nitrous gas were now slowly sent through it: it first became of a light olive, then of a dark olive, then of a muddy green, then of a bright green, and lastly of a blue green. After its assumption of this colour, the gas appeared to pass through it unaltered, and large glo-

* A pale acid of 1.52, by being converted into yellow acid, became nearly of specific gravity 1.51.

† It is impossible to ascertain the quantity of gas absorbed to more than a quarter of a cubic inch, as the first portions of nitrous gas thrown into the graduated cylinder are combined with the oxygen of the common air in it, to form nitrous acid, and hence the slight excess of weight.

bules of fluid, of a darker green than the rest, remained at the bottom of the cylinder, and when agitated, did not combine with it. The increase of weight was only one grain, and the acid was of specific gravity 1.474 nearly.

In this experiment it was evident that the unabsorbed nitrous gas had carried over with it a considerable quantity of nitrous acid. I endeavoured to correct the errors resulting from this circumstance, by connecting the curved tube first with a small water apparatus, and afterwards with a mercurial apparatus; but when the water apparatus was used, the greater part of the unabsorbed gas was dissolved with the nitrous acid it held in solution, by the water; and when mercury was employed, the nitrous acid that came over was decomposed, and the quantity of nitrous gas evolved, in consequence increased.

As it was possible that a small deficiency of weight might arise from the red vapour given out during the processes of weighing and examining the acid in the last experiment, 35 cubic inches of nitrous gas were very slowly passed through 90 grains of pale nitrous acid, of specific gravity 1.5: it became of similar appearance to that just described, had gained in weight 6.75 grains, and was become of specific gravity 1.475.

These experiments did not afford approximations sufficiently accurate towards the composition of deoxygenated acids, containing more nitrous gas than the dark orange coloured. To obtain them, a solution consisting of 94.25 grains of blue green, or perfectly nitrated acid, (if we may be allowed to employ the term,) of specific gravity 1.475, was inserted into a graduated phial, and connected by a curved tube, with the mercurial air-holder; in the conductor of which a small

quantity of water was inserted to absorb the nitrous acid which might be carried over by the gas. Heat was slowly applied to the phial, and nitrous gas given out with great rapidity. When 4 cubic inches were collected, the acid became dark olive; when 9, dark red; when 13, bright orange; and when 18, pale. It had lost 31 grains, and when completely cool, was of specific gravity 1.502 nearly. The water in the apparatus was tinged of a light blue; from whence we may conclude that some of the nitrous gas was absorbed by it with the nitrous acid; but it will be hereafter proved that the orange-coloured acid is the most nitrated acid capable of combining undecomposed with water, and that the colour it communicates to a large quantity of water, is light blue. If then we take 6.1 grains, the quantity of gas collected, from 31 the loss, the remainder is 24.9, which reasoning from the synthetical experiment, may be supposed to contain nearly three cubic inches of nitrous gas. Consequently, 94.25 grains of dark green acid, of specific gravity 1.475, are composed of nearly 21 cubic inches, or 7.2 grains of nitrous gas, and 87.05 grains of pale nitrous acid, of 1.504.

VIII. Comparing the different synthetical and analytical experiments, we may conclude with tolerable accuracy, that 9.275 grains of bright yellow, or standard acid of 1.5, are composed of 2.75 grains of nitrous gas, and 90 grains of nitric acid of 1.504; but 92.75 grains of standard acid contain 85.23 grains of nitrous acid, composed of about 27.23 of oxygen, and 58 nitrous gas: now from 58, take 2.75, and the remainder 55.25, is the quantity of nitrous gas contained in 90 grains of nitric acid of 1.504; consequently 100 grains of it are composed of 8.45 water, and 91.55 true acid, contain-

ing 61·32 nitrous gas, and 30·23 oxygen; or 27·01 nitrogen, and 64·54 oxygen, and the nitrogen in nitric acid, is to the oxygen as 1 to 2·389.

IX. My ingenious friend, Mr. James Thomson, has communicated to me some observations relating to the composition of nitrous acid (that is, the orange-coloured acid), from which he draws a conclusion which is, in my opinion, countenanced by all the facts we are in possession of, namely, "that it ought not to be considered as a distinct and less oxygenated state of acid, but simply as nitric or pale acid, holding in solution, that is, loosely combined with, nitrous gas." *

* In a letter to me, dated Oct. 28, 1799, after giving an account of some experiments on the phlogistication of nitric acid by heat and light, he says, "It was from an attentive examination of the manner in which the nitric acid was phlogisticated in these experiments, that I was confirmed in the suspicion I had long before entertained, of the real difference between the *nitrous* and *nitric* acids. It is not enough to shew that in the *nitrous* acid, (that is, the nitric holding nitrous gas in solution,) the proportion of oxygen in the whole compound is less than that entering into the composition of the nitric acid, and that it is therefore less oxygenated. By the same mode of reasoning we might prove that water, by absorbing carbonic acid gas, became less oxygenated, which is absurd. Should any one attempt to prove (which will be necessary to substantiate the generally received doctrine) that the oxygen of the nitrous gas combines with the oxygen of the acid, and the nitrogen, in like manner, so that the resulting acid, when nitrous gas is absorbed by nitric acid, is a binary combination of oxygen and nitrogen, he would find it somewhat more difficult than he at first imagined; it appears to me impossible. It is much more consonant with experiment to suppose that nitrous acid is nothing more than nitric acid holding nitrous gas in solution, which might in conformity to the principles of the French nomenclature, be called nitrate of nitrogen. The difficulty, and in some cases the impossibility, of forming nitrites, arises from the weak affinity which nitrous gas has for nitric acid, compared with that of other substances; and the decomposition of nitrous acid (that is, nitrate of nitrogen) by an alkaline or metallic substance, is perfectly analogous to the

It is impossible to call any substance a simple acid that is incapable of entering undecomposed into combination with the alkalis, &c.; but it will appear hereafter that the salts called in the new nomenclature *nitrites*, cannot be directly formed. If, indeed, it could be proved, that the heat produced by the combination of nitrous acid with salifiable bases, was the only cause of the partial decomposition of it, and that when this process was effected in such a way as to prevent increase of temperature, no nitrous gas was liberated, the common theory might have some foundation; but though dilute phlogisticated nitrous acid combines* with alkaline solutions without decomposition, yet no excess of nitrous gas is found in the solid salt: it is either disengaged in proportion as the water is evaporated, or it absorbs oxygen from the atmosphere, and becomes nitric acid.

In proportion as the nitrous acids contain more nitrous gas, so in proportion do they more readily give it out. From the blue green acid it is liberated slowly

decomposition of any other nitrate, the nitrous gas being displaced by the superior affinity of the alkali for the acid.

"Agreeable to this theory, the salts denominated *nitrites* are in fact triple salts, or ternary combinations of nitric acid, nitrous gas, and salifiable bases."

This theory is perfectly new to me. Other Chemists to whom I have mentioned it, have likewise considered it as new. Yet in a subsequent letter Mr. Thomson mentions that he had been told of the belief of a similar opinion among the French Chemists.

* In some experiments made on the nitrites of potash, and of ammonia, before I was well acquainted with the composition of nitric acid, I found that a light olive-coloured acid of 1.28, was capable of being saturated by weak solutions of potash and ammonia, without losing any nitrous gas; but after the evaporation of the neutralised solution, at very low temperatures, the salts in all their properties resembled *nitrates*.

at the temperature of 50° , and from the green likewise on agitation. The orange-coloured and yellow acids do not require a heat above 200° to free them of their nitrous gas; and all the coloured acids, when exposed to the atmosphere, absorb oxygen, and become by degrees pale.

If the nitrous vapour, *i.e.* such as is disengaged during the *denitration* of the coloured acids, was capable of combining with the alkalies, it might be supposed a distinct acid, and called nitrous acid; and the acids of different colours might be considered simply as compounds of this acid with nitric acid; but it appears to be nothing more than a solution of nitric acid in nitrous gas, incapable of condensation, undecompounded, and when decompounded and condensed, constituting the dark green acid, which is immiscible with water,* and uncombinable with the alkalies.†

It seems therefore reasonable, till we are in possession of new lights on the subject, to consider, with Mr. Thomson, the deoxygenated or nitrous acids simply as solutions of nitrous gas in nitric acid, and as analogous to the solutions of nitrous gas in the sulphuric and marine acids, &c. and the salts called nitrites, ternary combinations, similar to the triple compounds composed of sulphuric acid, metallic oxides, and nitrous gas.‡

Supposing the truth of these principles according to the logic of the French nomenclature, there is no acid to which the term nitrous acid *ought* to be applied; but as it has been used to signify the acids holding in solu-

* As is evident from the curious appearance of the dark green spherules, repulsive both to water, and light green acid.

† That is, undecompounded.

‡ The existence of these bodies will be hereafter proved.

tion nitrous gas, it is perhaps better still to apply it to those substances, than to invent for them new names. A nomenclature, accurately expressing their constituent parts, would be too complex, and like all other nomenclatures founded upon theory, liable to perpetual alterations. Their composition is known from their specific gravity and their colours; hence it is better to denote it by those physical properties: thus orange nitrous acid, of specific gravity 1.480, will signify a solution of nitrous gas in nitric acid, in which the nitric acid is to the nitrous gas, nearly as 87 to 5, and to the water as 11 to 1.

X. The estimation of the composition of the yellow and orange coloured nitrous acids given in the following table, may be considered as tolerably accurate, being deduced from the synthetical experiments in the sixth section, compared with the analytical ones. But as in the synthetical experiment, when the acid became green, it was impossible to ascertain the quantity of nitrous gas that passed through it unabsorbed, and as in the analysis the quantity of nitrous gas dissolved by the water at different periods of the experiment could not be ascertained, the accounts of the composition of the green acids must be considered only as very imperfect approximations to truth.

TABLE I.

CONTAINING APPROXIMATIONS TO THE QUANTITIES OF NITRIC ACID, NITROUS GAS, AND WATER IN NITROUS ACIDS, OF DIFFERENT COLOURS AND SPECIFIC GRAVITIES.

100 Parts.		Specific gra.		Nitric Acid.	Water.	Nitrous gas.
Sol. Nitric Acid	of	1.504	contain	91.55	8.45	—
Yellow Nitrous *		1.502		90.5	8.3	1.2
Bright Yellow		1.500		88.94	8.10	2.96
Dark Orange		1.480		86.84	7.6	5.56
Light Olive *		1.479		86.00	7.55	6.45
Dark Olive *		1.478		85.4	7.5	7.1
Bright Green *		1.476		84.8	7.44	7.76
Blue Green †		1.475		84.6	7.4	8.00

TABLE II.

BINARY PROPORTIONS OF OXYGEN AND NITROGEN IN NITRIC AND NITROUS ACIDS.‡

100 Parts.		Oxygen.	Nitrogen.		Nitrogen.	Oxygen.
Nitric Acid	contain	70.50	29.50	Proportions. Unity.	1	2.389
Bright yellow Nitrous		70.10	29.90		1	2.344
Orange coloured		69.63	30.37		1	2.292
Dark Green		69.08	30.92		1	2.230

XI. I have before mentioned that dilute nitric acids are incapable of dissolving so much nitrous gas in pro-

* The composition of the acids thus marked, is given from calculations.

† The blue green acid is not homogeneal in its composition, it is composed of the blue green spherules and the bright green acid. The blue green spherules are of greater specific gravity than the dark green acid, probably because they contain little or no water.

‡ Nitrous gas contains 44.05 nitrogen, and 55.25 oxygen, as has been said before.

portion to their quantities of true acid, as concentrated ones. During their absorption of it, they go through similar changes of colour; 330 grains of nitric acid, of specific gravity 1.36, after 50 cubic inches of gas had been passed through it, became blue green, and of specific gravity 1.351. It had gained in weight but 3 grains; and when the nitrous gas was driven from it by heat into a water apparatus, but 7 cubic inches were collected.*

From the diminution of specific gravity of nitric acid by combination with nitrous gas, and from the smaller attraction of nitric acid for nitrous gas, in proportion as it is diluted, it is probable that the nitrated acids, in their combinations with water, do not contract so much as† nitric acids of the same specific gravities. The affinities resulting from the small attraction of nitrous gas for water, and its greater attraction for nitric acid, must be such as to lessen the affinity of nitric acid and water for each other.

Hence it would require an infinite number of experiments to ascertain the real quantities of acid, nitrous gas, and water, contained in the different diluted nitrous acids; and after these quantities were determined, they would probably have no important connection with the chemical arrangement. As yet, our instruments of experiment are not sufficiently exact to afford us the means of ascertaining the ratio in which the attraction of nitric acid‡ for water diminishes in its progress towards saturation.

* A great portion of it, of course, dissolved in the water with the nitrous acid carried over.

† Their changes of volume, corresponding to changes of temperature, most probably, are likewise different.

‡ Probably in the ratio of the square of the quantity of water united to it.

The estimations in the following table, of the real quantities of nitric acid in solutions of different specific gravities, were deduced from experiments made in the manner described in section 6, except that the phial employed was longer, narrower, and graduated to half grains. The temperature, at the time of combination, was from 40° to 46°.

TABLE III.
OF THE QUANTITIES OF TRUE NITRIC ACID IN SOLUTIONS OF
DIFFERENT SPECIFIC GRAVITIES.

100 Parts Nitric Acid of specific gravity		True Acid.*	Water.
1.5040	contain	91.55	8.45
1.4475		80.39	19.61
1.4285		71.65	28.35
1.3906		62.96	37.04
1.3551		56.88	43.12
1.3186		52.03	47.97
1.3042		49.04	50.96
1.2831		46.03	53.97
1.2090		45.27	54.73

XII. The blue green spherules mentioned in section 5, produced by the condensation of nitrous vapour, and by the condensation of nitric acid with nitrous gas, may be considered as saturated solutions of nitrous gas in nitric acid. The combinations of nitric acid and nitrous gas containing a larger proportion of nitrous gas, are incapable of existing in the fluid state at common temperatures; and, as appears from the first experiment, an increase of volume takes place during their forma-

* The quantities of oxygen and nitrogen in any solution, may be thus found — Let A = the true acid, X the oxygen, and Y the nitrogen,

$$\text{Then } X = \frac{238 A}{29} \text{ and } Y = \frac{A}{239}$$

tion. They consequently ought to be looked upon as solutions of nitric acid in nitrous gas, identical with the nitrous vapour of Priestley.

From the researches of this great discoverer, we learn that nitrous vapour is decomposable, both by water and mercury. Hence it is almost impossible accurately to ascertain its composition. In one of his experiments,* when more than 130 grains of strong nitrous acid were exposed for two days to nearly 247 cubic inches of nitrous gas, over water, about half of the acid was dissolved, and deposited with the gas in the water.†

XIII. In comparing the results of my fundamental experiment on the composition of nitrous acid, with those of Cavendish, the great coincidence between them gave me very high satisfaction, as affording additional proofs of accuracy. If the acid formed in the last experiment of this illustrious philosopher be supposed analogous to the light green acid formed in my first experiment, our estimations will be almost identical.

Lavoisier's account of the composition of the nitric and nitrous acids, has been generally adopted. According to his estimation, these substances contain a much larger quantity of oxygen than I have assigned to them.

The fundamental experiments of this great philosopher were made at an early period of pneumatic chemistry,‡ on the decomposition of nitre by charcoal; and he considered the nitrogen evolved, and the oxygen of

* Experiments and Observations; last edition, vol. i. p. 384.

† Nitrous gas, holding in solution nitrous acid, is more readily absorbed by water than when in its pure form, from being presented to it in a more condensed state in the green acid, formed by the contact of water and nitrous vapour.

‡ Mem. des Savans Etrangers, vol. xi. 226. Vide Kirwan sur le Philogistique, p. 110.

the carbonic acid produced in this process, as the component parts of the nitric acid contained in the nitre.

I have before mentioned the liberation of nitrous acid, in the decomposition of nitre by the combustible bodies; and I had reasons for suspecting that this circumstance was not the only source of inaccuracy.

That my suspicions were well founded, will appear from the following experiments:—

EXPERIMENT a. I introduced into a strong glass tube, 3 inches long, and nearly $\cdot 3$ wide, a mixture of 10 grains of pulverised, well burnt charcoal, and 60 grains of nitre. It was fired by means of touch-paper, and the tube instantly plunged under a jar filled with dry mercury. A quantity of gas, clouded with dense white vapour was collected. When this vapour was precipitated, so that the surface of the mercury could be seen, it appeared white, as if acted on by nitrous acid. On introducing a little oxygen into the jar, copious red fumes appeared.

EXP. b. A similar mixture was fired* under the jar, the top of the mercury being covered with a small quantity of red cabbage juice, rendered green by an alkali. This juice, examined when the vapour was precipitated, was become red, and on introducing to it a little carbonate of potash, a slight effervescence took place.

EXP. c. Five grains of charcoal, and 20 of nitre, were now fired in the same manner as before, the mercury being covered with a stratum of water. After the precipitation of the vapour on the introduction of oxygen, no red fumes were perceived.

EXP. d. 30 grains of nitre, 5 of charcoal, and 5 of

* In this experiment, as well as in the last, some of the mixture was thrown into the jar undecomposed.

silicious earth,* were now mingled and fired. The gas received under mercury was composed of 18 carbonic acid, and nearly 12 nitrogen.† A little muriatic acid was poured on the residuum in the tube; a slight effervescence took place.

Exp. e. The top of the mercury in the jar was now covered with a little diluted muriatic acid, and a small glass tube filled with a mixture of 3 grains of charcoal, and 20 nitre. After the deflagration, the tube itself with the residuum it contained, were thrown into the jar. The carbonic acid was quickly detached from them by the muriatic acid, and the whole quantity of gas generated in the process, obtained; it measured 15 cubic inches.

4 cubic inches of it exposed to solution of potash, diminished to $1\frac{4}{10}$; 7 of the remainder, with 8 of oxygen, gave only 12.

Exp. f. 60 grains of nitre, and 9 of charcoal were fired, the top of the mercury in the jar being covered with water. After the deflagration, the tube that had contained them was introduced, and the carbonic acid contained by the carbonate of potash, disengaged by muriatic acid. 30 measures of the gases evolved were exposed to caustic potash: 20 exactly were absorbed, the 10 remaining, with 10 of oxygen, diminished to 17.

Exp. g. A mixture of nitre and charcoal were deflagrated over a little water in the mercurial jar: after the precipitation of the vapour, the water was absorbed by filtrating paper. This filtrating paper, heated in a solution of potash, gave a faint smell of ammonia.

* To detach the potash from the carbonic acid.

† This nitrogen contained a little nitrous gas, as it gave red fumes when exposed to the air. The free nitrous acid was decomposed by the mercury, as it was not covered with water.

EXP. *h.* Water impregnated with the vapour produced in the deflagration was heated with quicklime, and presented separately to three persons accustomed to chemical odours. Two of them instantly recognised the ammoniacal smell, the other could not ascertain it. Paper reddened with cabbage juice was quickly turned green by the vapour.

These experiments are sufficient to shew that the decomposition of nitre by charcoal is a very complex process, and that the intense degree of heat produced may effect changes in the substances employed, which we are unable to estimate.

The products, instead of being simply carbonic acid, and nitrogen, are carbonic acid, nitrogen, nitrous acid, probably ammonia, and sometimes nitrous gas. The nitrous acid is disengaged from the base by the intense heat. Concerning the formation of the ammonia, it is useless to reason till we have obtained unequivocal testimonies of its existence; it may be produced either by the decomposition of the water contained in the nitre, by the combination of its oxygen with the charcoal, and of its nascent hydrogen with nitrogen of the nitric acid; or from some unknown decomposition of the potash.

As neither Lavoisier nor Berthollet found nitrous gas produced in the decomposition of nitre by charcoal, when a water apparatus was employed; and as it was not uniformly evolved in my experiments, the most probable supposition is, that it arises from the decomposition of a portion of the free nitrous acid intensely heated, by the mercury.

In none of my experiments was the whole of the nitre and charcoal decomposed, some of it was uniformly thrown with the gases into the mercurial apparatus. The nitrogen evolved, as far as I could ascertain by

the common tests, was mingled with no inflammable gas.

If we consider experiment *f* as accurate with regard to the relative quantities of carbonic acid and nitrogen produced, they are to each other nearly as 20 to 8; that is, allowing 2 for the nitrous gas, and consequently, reasoning in the same manner as Lavoisier, concerning the composition of nitric acid, it should be composed of 1 nitrogen to 3.38 oxygen. But though the quantity of oxygen in this estimation is far short of that given in his, yet still it is too much. From whatever source the errors arise, whether from the evolution of phlogisticated nitrous acid, or the decomposition of water, or the production of nitrous gas, they all tend to increase the proportion of the carbonic acid to the nitrogen.

I am unacquainted with any experiment from which accurate opinions concerning the different relative proportions of oxygen and nitrogen in the nitric and nitrous acids could be deduced. Lavoisier's calculation is founded on his fundamental experiment, and on the combination of nitrous gas and oxygen.

Dr. Priestley's experiment, mentioned in section 12, on the absorption of nitrous gas by nitrous acid, from which Kirwan* deduces the composition of the differently-coloured nitrous acids, was made over water, by which, as is evident from a minute examination of the facts, † the greater portion of the nitrous gas employed was absorbed.

* Essay on Phlogiston.

† Dr. Priestley says: "Having filled a phial containing exactly the quantity of four pennyweights of water, with strong, pale, yellow spirit of nitre, with its mouth quite close to the top of a large receiver standing in water, I carefully drew out almost all the common air, and then filled it with nitrous air; and as this was absorbed, I kept putting in more and more, till in less than two days it had completely absorbed 130

XIV. The opinions heretofore adopted respecting the quantities of real or true acid in solutions of nitrous acid of different specific gravities, have been founded on experiments made on the nitro-neutral salts, the most accurate of which are those of Kirwan, Bergman and Wenzel. The great difference in the results of these celebrated men, proves the difficulty of the investigation, and the existence of sources of error. * Kirwan deduces the composition of the solutions of nitrous acid in water, from an experiment on the formation of nitrated soda. In this experiment, 36.05 grains of soda were saturated by 145 grains of nitrous acid, of specific gravity 1.2754. By a test experiment, he found the quantity of salt formed to be 85.142 grains. † Hence he concludes that 100 parts of nitrous acid, of specific gravity 1.5543, contain 73.54 of the strongest, or most concentrated acid.

Supposing his estimation perfectly true, 100 parts of the aëriform acid of 55° would be composed of 74.54 of his real acid, and 25.46 water. In examining, however, one of his later experiments, ‡ we shall find reasons for concluding, that the acid in nitrated soda cannot contain much less water than the aëriform acid. A so-

ounce measures. Presently after this process began, the surface of the acid assumed a deep orange colour, and when 20 or 30 ounce measures of air were absorbed, it became green at the top: this green descended lower and lower, till it reached the bottom of the phial. Towards the end of the process, the evaporation was perceived to be very great, and when I took it out, the quantity was found to have diminished to one half. Also it had become, by means of this process, and the evaporation together, exceeding weak, and was rather blue than green."

Experiments and Observations, vol. 1, p. 384.

* See Mr. Keir's excellent observations on this subject, *Chem. Dict. Art. Acid.*

† *Irish Transactions*, vol. 4, p. 34.

‡ *Addit. Obs.* page 74.

lution of carbonated soda, containing 125 grains of real alkali, was saturated by 306·2 grains of nitrous acid, of specific gravity 1·416. The evaporation was carried on in a temperature not exceeding 120°, and the residuum exposed to a heat of 400° for six hours, at the end of which time it weighed 308 grains. Now according to my estimation, 306 grains of nitric acid, of 1·416, should contain 215 true acid; and we can hardly suppose, but that during the evaporation and consequent long exposure to heat, some of the nitrated soda was lost with the water.

Bergman estimates the quantity of water in this salt at 25, and the acid at 43 per cent.; but his real acid was not so concentrated as Kirwan's, consequently the nitric acid in nitrated soda should contain more water than my true acid.

Wenzel, from an experiment on the composition of nitrated soda, concludes that it contains 37·48 of alkali, and 62·52 of nitrous acid; and 1000 of this acid, from Kirwan's calculation, contain 812·6 of his real acid; consequently, 100 parts of my æriform acid should contain 93·28 of Wenzel's acid, and 6·72 of water.

I saturated with potash 54 grains of solution of nitric acid, of specific gravity 1·301. Evaporated at about 212°, it produced 66 grains of nitre. This nitre exposed to a higher temperature, and kept in fusion for some time, was reduced to 60 grains.

Now from the table, 54 of 1·301, should contain 26·5 of true acid. But according to Kirwan's estimation, 100 parts of dry nitre contain 44* of his real acid, with 4 water; consequently, 60 should contain 26·4.

Again, 90 grains of acid, of specific gravity 1·504, saturated with potash, and treated in the same manner,

* Additional Observations, page 70.

gave 173 grains of dry nitre. Consequently, 100 parts of it should contain 47·3 grains of true acid.

Now Lavoisier* allows about 51 of dry acid to 100 grains of nitre, and Wenzel 52.

From Berthollet's† experiments, 100 grains of nitre, in their decomposition by heat, give out nearly 49 grains of gas.‡

Hence it appears that the aëriform acid, that is, the true acid of my table, contains rather less water than the acid supposed to exist in nitre. §

DIVISION II.

EXPERIMENTS AND OBSERVATIONS ON THE COMPOSITION OF AMMONIA AND ON ITS COMBINATIONS WITH WATER AND NITRIC ACID.

I. *Analysis of Ammonia or Volatile alkali.*

THE formation and decomposition of volatile alkali in many processes, was observed by Priestley, Scheele, Bergman, Kirwan, and Higgins; but to Berthollet we owe the discovery of its constituent parts, and their proportions to each other. These proportions this excellent philosopher deduced from an experiment on the decomposition of aëriform ammonia by the electric

* Elements, p. 103, Kerr's Translation.

† Mem. Acad. 1787.

‡ As well as oxygen and nitrogen. Mr. Watt's experiments prove that much phlogisticated nitrous acid is produced.

§ [For the results of the Author's later researches relative to the composition and properties of nitric acid and nitrous acid gas, &c., vide Elements of Chemical Philosophy, article Azote.]

spark : * a process in which no apparent source of error exists.

Since, however, his estimations have been made, the proportions of oxygen and hydrogen in water have been more accurately determined. This circumstance, as well as the conviction of the impossibility of too minutely scrutinizing facts, fundamental to a great mass of reasoning, induced me to make the following experiments.

A porcelain tube was provided, open at both ends, and well glazed inside and outside, its diameter being about $\cdot 5$ inch. To one end of this, a glass tube was affixed, curved for the purpose of communicating with the water apparatus. With the other end a glass retort was accurately connected, containing a mixture of perfectly caustic slacked lime, and muriate of ammonia.

The water in the apparatus for receiving the gases had been previously boiled, to expel the air it might contain, and during the experiment was yet warm.

When the tube had been reddened in a furnace adapted to the purpose, the flame of a spirit lamp was applied to the bottom of the retort. A great quantity of gas was collected in the water apparatus; of this the first portions were rejected, and the last transferred to the mercurial trough.

A small quantity examined, did not at all diminish with nitrous gas, and burnt with a lambent white flame, in contact with common air.

$2\frac{3}{4}$ of this gas, equal to 110 grain measures, were fired with 2, equal to 80, of oxygen, in a detonating tube, by the electric spark. They were reduced to $2\frac{1}{4}$, or 90. On introducing to the remainder a solution of strontian, it became slightly clouded on the

* *Journal de Physique*, 1786, tom. ii. page 176.

top, and an absorption of some grain measures took place.

It was evident, then, that in this experiment, charcoal* had been somehow present in the tube; which being dissolved by the nascent hydrogen, had rendered it slightly carbonated, and in consequence made the results inconclusive.

A tube of thick green glass carefully made clean, was now employed, inclosed in the porcelain tube. Every other precaution was taken to prevent the existence of sources of error, and the experiment conducted as before.

140 grain measures of the gas produced, fired with 120 of oxygen, left, in two experiments, nearly 110. Solution of strontian placed in contact with the residuum, did not become clouded, and no absorption was perceived.

Now 150 measures of gas were destroyed, and if we take Lavoisier's and Meusnier's estimation of the composition of water, and suppose the weight of oxygen to be 35 grains, and that of hydrogen 2·6 the hundred cubic inches; the oxygen employed will be to the hydrogen as 243 to 576. Put x for the oxygen, and y for the hydrogen.

$$\begin{array}{rcl}
 \text{Then} & x + y = 150 & \\
 & x : y :: 243 : 576 & \\
 & x = \frac{243 y}{576} & \\
 & 819 y = 86400 & \\
 & y = 105 & x = 45 \\
 \text{And} & 140 - 105 = 35 &
 \end{array}$$

* Though the tube had never been used, and was apparently clean and dry on the inside, it must have contained something in the form of dust, capable of furnishing either hydro-carbonate, or charcoal.

Consequently, the nitrogen in ammonia is to the hydrogen as 35 : 105 in volume; and 13·3 grains of ammonia are composed of 10·6 nitrogen, (supposing that 100 cubic inches weigh 30·45 grains) and 2·7 hydrogen.

According to Berthollet, the weight of the nitrogen in ammonia is to that of the hydrogen as 121 to 29.* The difference between this estimation and mine is so small as to be almost unworthy of notice, and arises most probably from the slight difference between the accounts of Lavoisier and Monge, of the composition of water, and the different weights assigned to the gases employed.

We may then conclude, that 100 grains of ammonia are composed of about 80 nitrogen, and 20 hydrogen.

The decomposition of ammonia by heat, as well as by the electric spark, was first discovered by Priestley. In an experiment † when aëriform ammonia was sent through a heated tube from a caustic solution of ammonia in water, this great discoverer observed that an inflammable gas was produced, though in no great quantity, and that a fluid blackened by matter, probably carbonaceous, likewise came over.

In my experiments the whole of the ammonia appeared to be decomposed; the quantity of gas generated was immense, and not clouded, as is usually the case with gases generated at high temperatures. It is possible, that the larger quantity of water carried over in his experiment, by its strong attraction for ammonia in the aëriform state, might have, in some measure, retarded the decomposition. It is, however, more probable to suppose, that a fissure existed in the earthen tube he

* *Journal de Physique*, 1786, t. ii. 177.

† *Phil. Trans.* vol. 79, page 294.

employed, through which a certain quantity of gas escaped, and coaly matter entered.

Priestley found that the metallic oxides when strongly heated, decomposed ammonia, the metal being revived and water and nitrogen produced.* The estimations of the composition of ammonia that may be deduced from his experiments on the oxide of lead, differ very little from those already detailed.

II. *Specific Gravity of Ammonia.*

From the great solubility of ammonia in water, it is difficult to ascertain its specific gravity in the same manner as that of a gas combinable to no great extent with that fluid. It is impossible to prevent the existence of a small quantity of solution of ammonia in the mercurial air-holder,† or apparatus containing the gas; and during the diminution of the pressure of the atmosphere on this solution,‡ a certain quantity of gas is liberated from it, and hence a source of error.

To ascertain, then, the weight of ammonia, I employed an apparatus similar to that used for the absorption of nitrous gas by nitric acid.

50 cubic inches of gas were collected in the mercurial air-holder, from the decomposition of muriate of ammonia by lime; thermometer being 58°, and barometer 29.6.

100 grains of diluted sulphuric acid were introduced into the small graduated cylinder, which after being

* Vol. ii. page 398.

† Ammonia generated at a temperature above that of the atmosphere, always deposits ammoniacal solution during its reduction to the common temperature.

‡ By the introduction of aëriform ammonia into the exhausted globe.

carefully weighed, was made to communicate with the air-holder, the curved tube containing a small quantity of water. The gas was slowly passed into the fluid, and the globules wholly absorbed before they reached the top; much increase of temperature being consequent. When the absorption was complete, the phial was increased in weight exactly 9 grains.

This experiment was repeated three times. The difference of weight, which was probably connected with alterations of temperature and pressure, never amounted to more than one-sixth of a grain.

We may then conclude, that at temperature 58° , and atmospheric pressure 29.6, 100 cubic inches of ammonia weigh 18 grains.

According to Kirwan, 100 cubic inches of alkaline air * weigh 18.16 grains; barometer 30° , thermometer 61° . The difference between these estimations, the corrections for temperature and pressure being made, is trifling.

III. *Of the Quantities of true Ammonia in Aqueous Ammoniacal Solutions, of different specific Gravities.*

To ascertain the quantities of ammonia, such as exists in the aëriform state, saturated with moisture, in solutions of different specific gravities, I employed the apparatus for absorption so often mentioned. Thermometer being 52° , the mercurial air-holder was filled with ammoniacal gas, and the graduated phial, containing 50 grains of pure water connected with it. During the absorption of the gas, the phial became warm. When about 30 cubic inches had been passed through, it was suffered to cool, and weighed: it had gained 5.25

* Additional Observations, page 107.

grains, and the fluid filled a space equal to that occupied by 57* grains of water.

Consequently, 100 grains of solution of ammonia in water of specific gravity, .9684 contain 9.502 grains of ammonia.

The apparatus being adjusted as before, 50 grains of pure water were now perfectly saturated with ammonia. They gained in weight 17 grains, and when perfectly cool, filled a space equal to 74 of water. Consequently 100 grains of aqueous ammoniacal solution of specific gravity .9054, contain 25.37 grains of ammonia.

The two solutions were mingled together, but no alteration of temperature took place. Consequently the resulting specific gravity might have been found by calculation.

On mingling a large quantity of caustic solution of ammonia with one-fourth of its weight of water, of exactly the same temperature, no alteration of it was perceptible by a sensible thermometer. Hence the two experiments† being assumed as data, the intermediate estimations in the following table were found by calculation.

* It is necessary in these experiments, that the greatest care be observed in the introduction and extraction of the capillary tube. If it is introduced dry, there will be a source of error from the moisture adhering to it when taken out. I therefore always wetted it before its introduction, and took care that no more fluid adhered to it after the experiment, than before.

† Previous to those experiments, I had made a number of others on the combination of ammonia with water. My design was, to ascertain the diminution of specific gravity for every three grains of ammonia absorbed; but this I found impossible. The capillary tube, when taken out of the phial, always carried with it a minute portion of the solution, which partially evaporated before it could be again introduced; and thus the sources of error increased in proportion to the number of examinations.

TABLE IV.*

OF APPROXIMATIONS TO THE QUANTITIES OF AMMONIA, SUCH AS EXISTS IN THE AERIFORM STATE, SATURATED WITH WATER AT 52°, IN AQUEOUS AMMONIACAL SOLUTIONS OF DIFFERENT SPECIFIC GRAVITIES.

100 Specific gra.		Ammonia.	Water.
9054	contain	25·37	74·63
9166		22·07	77·93
9255		19·54	80·46
9326		17·52	82·48
9385		15·88	84·12
9435		14·53	85·47
9476		13·46	86·54
9513		12·40	87·60
9545		11·56	88·44
9573		10·82	89·18
9597		10·17	89·83
9619		9·60	90·40
9684		9·50	90·5
9639		9·09	90·91
9713		7·17	92·83

That no considerable source of error existed in the two experiments, is evident from the trifling difference between the estimations of the quantities of real ammonia, in the solution of ·9684, as found in the first experiment, and as given by calculation from the last.

The quantity of ammonia in a solution of specific gravity not in the table, may be thus determined:—Find the difference between the two specific gravities

* As yet no mode has been discovered for obtaining gases in a state of absolute dryness ; consequently, we are ignorant of the different quantities of water they hold in solution at different temperatures. As far as we are acquainted with the combinations of ammonia, there is no state in which it exists so free from moisture, as when æriform at low temperatures.

nearest to it in the table, d , and the difference between their quantities of alkali, b ; likewise the difference between the given specific gravity and that nearest to it, c .

then $d : b :: c : x$ and $x = \frac{b c}{d}$

Which, added to the quantity of the lower specific gravity, is the alkali sought.

The differences in specific gravity of the solutions of ammonia at temperatures between 40° and 65° * are so trifling as to be hardly ascertainable by our imperfect instruments, and consequently are unworthy of notice.

It is possible at very low temperatures to obtain ammoniacal solutions of less specific gravity than $\cdot 9$, but they are incapable of being kept for any length of time under the common pressure of the atmosphere.

IV. *Combinations of Ammonia with Nitric Acid. Composition of Nitrate of Ammonia, &c.*

200 grains of ammoniacal solution, of specific gravity $\cdot 9056$, were saturated by $385\cdot 5$ grains of nitric acid, of specific gravity $1\cdot 306$. The combination was effected in a long phial, the nitrous acid added very slowly, and the phial closed after every addition, to prevent any evaporation in consequence of the great increase of temperature.† The specific gravity of the solution, when reduced to the common temperature, was $1\cdot 15$. Evaporated at a heat of 212° ,‡ it gave 254

* The expansion from increase of temperature is probably great in proportion to the quantity of ammonia in the solution.

† From the combination.

‡ I had before proved that at this temperature the salt neither decomposed nor sublimed.

grains of salt of fibrous crystallization. This salt was dissolved in 331 grains of water; the specific gravity of the solution was 1.148 nearly.

Hence it is evident that some of the salt had been lost during the evaporation.

To find the quantity lost, fibrous nitrate of ammonia was dissolved in small quantities in the solution, the specific gravity of which was examined after every addition of three grains. When 16 grains had been added to it, it became of 1.15.

Consequently, the solution composed of 200 grains of ammoniacal, and of 385.5 of nitric acid solution, contained 262 grains of salt of fibrous crystallization, and of this salt 8 grains were lost during the evaporation.

But the alkali in 200 grains of ammoniacal solution of .9056 = 50.5 grains. And the true nitric acid in 385.5 grains of solution of 1.306 = 190 grains.

Then $262 - 240.5 = 21.5$, the quantity of water.

And 262 grains of fibrous crystallized nitrate of ammonia, contain 190 grains true acid, 50.5 ammonia, and 21.5 water. And 100 parts contain 72.5 acid, 19.3 ammonia, and 8.2 water.

In proportion as the temperature employed for the evaporation of nitro-ammoniacal solutions, is above or below 212° , so in proportion does the salt produced contain more or less water than the fibrous nitrate. But whatever may have been the temperature of evaporation, the acid and alkali appear always to be in the same proportions to each other.

Of the salts containing different quantities of water, two varieties must be particularly noticed. The prismatic nitrate of ammonia, produced at the common temperatures of the atmosphere, and containing its full quantity of water of crystallization; and the compact

nitrate of ammonia, either amorphous, or composed of delicately needled crystals, formed 300° , and containing but little more water than exists in nitric acid and ammonia.

To discover the composition of the prismatic nitrate of ammonia, 200 grains of fibrous salt were dissolved in the smallest possible quantity of water, and evaporated in a temperature not exceeding 70° . The greater part of the salt was composed of perfectly formed tetrahædral prisms, terminated by tetrahædral pyramids. It had gained in weight about 8.5 grains.

Consequently, 100 grains of prismatic nitrate of ammonia may be supposed to contain 69.5 acid, 18.4 ammonia, and 12.1 water.

To ascertain the composition of the compact nitrate of ammonia, I exposed in a deep porcelain cup, 400 grains of the fibrous salt, in a temperature below 300° . It quickly became fluid, and slowly gave out its water without any ebullition, or liberation of gas. When it was become perfectly dry, it had lost 33 grains. I suspected that in this experiment some of the salt had been carried off with the water; to determine this, I introduced into a small glass retort, 460 grains of fibrous salt; it was kept at a heat below 320° , in communication with a mercurial apparatus, in a regulated air-furnace, till it was perfectly dry: it had lost 23 grains. No gas, except the common air of the retort came over, and the fluid collected had but a faint taste of nitrate of ammonia.

Though in this experiment I had removed all the fluid retained in the neck of the retort, still a few drops remained in the head, and on the sides, which I could not obtain. It was of importance to me to be accurately acquainted with the composition of the compact

salt, and for that reason I compared these analytical experiments with a synthetical one.

I saturated 200 grains of solution of ammonia of $\cdot 9056$ with acid, ascertained the specific gravity of the solution, evaporated it at 212° , and fused and dried it about 300° — 260° . It gave 246 grains of salt, and a solution made of the same specific gravity as that evaporated, indicated a loss of 9 grains. Consequently, 255 grains of this salt contain 50.5 grains alkali, 190 grains acid, and 14.5 grains water.

We may then conclude, that 100 parts of compact nitrate of ammonia contain 74.5 acid, 19.8 alkali, and 5.7 water.

V. *Decomposition of Carbonate of Ammonia by Nitric Acid.*

In my first experiments on the production of nitrate of ammonia, I endeavoured to ascertain its composition by decomposing carbonate of ammonia by nitric acid; and in making for this purpose, the analysis of carbonate of ammonia, I discovered that there existed many varieties of this salt, containing very different proportions of carbonic acid, alkali, and water: the carbonic acid and water being superabundant in it, in proportion as the temperature of its formation was low, and the alkali in proportion as it was high: and not only that a different salt was formed at every different temperature, but likewise that the difference in them was so great, that the carbonate of ammonia formed at 300° contained more than 50 per cent. alkali, whilst that produced at 60° contained only 20.*

* A particular account of the experiments from which these facts were

I found 210 grains of carbonate of ammonia, which from comparison with other salts previously analyzed, I suspected to contain about 20 or 21 per cent. alkali, saturated by 200 grains of nitric acid of 1.504. But though the carbonate was dissolved in much water, still, from the smell of the carbonic acid generated, I suspect that a small portion of the nitric acid was dissolved, and carried off by it. The solution, evaporated at about 200°, and afterwards exposed to a temperature below 300°, gave 232 grains of compact salt. But reasoning from the quantity of acid in 200 grains of nitric acid of 1.504, it ought to have given 245. Consequently 13 were lost by evaporation; and this loss agrees with that in the other experiments.

V. *Decomposition of Sulphate of Ammonia by Nitre.*

As a cheap mode of obtaining nitrate of ammonia, Dr. Beddoes proposed to decompose nitre by sulphate of ammonia, which is a well-known article of commerce. From synthesis of sulphate of ammonia, compared with analysis made in August, 1799,* I concluded that 100

deduced was printed in September, and will appear in the first volume of the *Researches*.(a)

* And which will be published, with an account of its perfect decomposition at a high temperature, in the *Researches*.

(a) [Since the above was written, the combinations of ammonia and carbonic acid have been carefully investigated, and the existence of three definite compounds determined, viz. a carbonate, sesquicarbonate, and bicarbonate—and further, a hydrated carbonate—a deliquescent very pungent salt, consisting of one proportion of water as well as of one of alkali and acid.—For some remarks on the author's early experiments, vide my paper on the combinations of carbonic acid and ammonia in *Edinburgh New Philosophical Journal* for April, 1834.]

[Whether the *Researches* alluded to in the above note were published, I do not know: I infer not—I have not been able to collect any information respecting them.]

grains of prismatic salt were composed of about 18 grains ammonia, 44 acid, and 38 water; and supposing 100 grains of nitre to contain 50 acid, 100 grains of sulphate of ammonia will require for their decomposition 134 grains of nitre, and form 90.9 grains of compact nitrate of ammonia.

To ascertain if the sulphate of potash and nitrate of ammonia could be easily separated, I added to a heated saturated solution of sulphate of ammonia, pulverised nitre, till the decomposition was complete. After this decomposition, the solution contained a slight excess of sulphuric acid, which was combined with lime, and the whole set to evaporate at a temperature below 250°. As soon as the sulphate of potash began to crystallize the solution was suffered to cool, and then poured off from the crystallized salt, which appeared to contain no nitrate of ammonia. After a second evaporation and crystallization, almost the whole of the sulphate appeared to be deposited, and the solution of nitrate of ammonia was obtained nearly pure: it was evaporated at 212°, and gave fibrous crystals.

VI. *Non-existence of Ammoniacal Nitrites.*

I attempted in different modes to combine *nitrous* acids with ammonia, so as to form the salts which have been supposed to exist, and called *nitrites* of ammonia; but without success.

I first decomposed a solution of carbonate of ammonia by dilute olive-coloured acid; but in this process, though no heat was generated, yet all the nitrous gas appeared to be liberated with the carbonic acid.*

* When nitrous gas exists in neutro-saline solutions, they are always coloured more or less intensely, from yellow to olive, in proportion to the quantity combined with them.

I then combined a small quantity of nitrous gas, with a solution of nitrate of ammonia. But after evaporating this solution at 70° — 80° , I could not detect the existence of nitrous gas in the solid salt; it was given out during the evaporation and crystallization, and formed into nitrous acid by the oxygen of the atmosphere. I likewise heated nitrate of ammonia to different degrees, and partially decomposed it, to ascertain if in any case the acid was phlogisticated by heat: but in no experiment could I detect the existence of *nitrous* acid in the heated salt, when it had been previously perfectly neutralized.

When nitrate of ammonia, indeed, with excess of nitric acid, is exposed to heat, the superabundant nitric acid becomes phlogisticated, and is then liberated from the salt, which remains neutral.*

We may therefore conclude that nitrous gas has little or no affinity for solid nitrate of ammonia, and that no substance exists to which the name *nitrite* of ammonia can with propriety be applied.

VII. *Of the Sources of Error in Analysis.*

To compare my synthesis of nitrate of ammonia with analysis, I endeavoured to separate the ammonia and nitric acid from each other, without decomposition. But in going through the analytical process, I soon discovered that it was impossible to make it accurate, without many collateral laborious experiments on the quantities of ammonia soluble in water at different temperatures.

* Hence a nitrate of ammonia with excess of acid, when exposed to heat, first becomes yellow, and then white.

At a temperature above 212° , I decomposed, by caustic slacked lime, 50 grains of compact nitrate of ammonia in a retort communicating with the mercurial air-holder, the moisture in which had been previously saturated with ammonia. 22 cubic inches of gas were collected at 38° , and from the loss of weight of the retort, it appeared that 13 grains of solution of ammonia in water, had been deposited by the gas.

Now evidently, this solution must have contained much more alkali in proportion to its water than that of 55° , otherwise the quantity of ammonia in 50 grains of salt would hardly equal 8 grains.*

VIII. *Of the Loss of Solutions of Nitrate of Ammonia during Evaporation.*

The most concentrated solution of nitrate of ammonia capable of existing at 60° , is of specific gravity 1.304, and contains 33 water, and 67 fibrous salt, per cent. When this solution is evaporated at temperatures between 60° and 100° , the salt is increased in weight by the addition of water of crystallization, and no portion of it is lost.

During the evaporation of solutions of specific gravity 1.146 and 1.15, at temperatures below 120° , I have never detected any loss of salt. When the temperature of evaporation is 212° , the loss is generally from 3 to 4

* The accounts given by different chemists of the composition of nitrate of ammonia, are extremely discordant; they have been chiefly deduced from decompositions of carbonate of ammonia (the varieties of which have been heretofore unknown) by nitrous acids of unknown degrees of nitration. Hence they are particularly erroneous with regard to the alkaline part. Wenzel supposes it to be 32 per cent, and Kirwan 24. Addit. Observ. pag. 120.

grains per cent.; and when from 230° to the standard of their ebullition, from 4 to 6 grains.

In proportion as solutions are more diluted, their loss in evaporation at equal temperatures is greater.

DIVISION III.

DECOMPOSITION OF NITRATE OF AMMONIA ; PREPARATION OF RESPIRABLE NITROUS OXIDE; ITS ANALYSIS.

I. *Of the Heat required for the Decomposition of Nitrate of Ammonia.*

THE decomposition of nitrate of ammonia has been supposed by Cornette* to take place at temperatures below 212° , and its sublimation at 234° .

Kirwan, from the non-coincidence in the accounts of its composition, has imagined that it is partially decomposable, even by a heat of 80° .†

To ascertain the changes effected by increase of temperature in this salt, a glass retort was provided, tubulated for the purpose of introducing the bulb of a thermometer. After it had been made to communicate with the mercurial air-holder, and placed in a furnace, the heat of which could be easily regulated, the thermometer was introduced, and the retort filled with the salt, and carefully luted; so that the appearances produced by different temperatures could be accurately observed, and the products evolved obtained.

From a number of experiments made in this manner on different salts, the following conclusions were drawn.

* Mem. Par. 1783. See Irish Trans. vol. iv.

† Addit. Obs. pag. 120.

1st. Compact, or dry nitrate of ammonia, undergoes little or no change at temperatures below 260° .

2dly. At temperatures between 275° and 300° , it slowly sublims, without decomposition, or without becoming fluid.

3dly. At 320° it becomes fluid, decomposes, and still slowly sublims; it neither assuming, nor continuing in, the fluid state, without decomposition.

4thly. At temperatures between 340° and 480° , it decomposes rapidly.

5thly. The prismatic and fibrous nitrates of ammonia become fluid at temperatures below 300° , and undergo ebullition at temperatures between 360° and 400° , without decomposition.

6thly. They are capable of being heated to 430° , without decomposition, or sublimation, till a certain quantity of their water is evaporated.

7thly. At temperatures above 450° they undergo decomposition, without previously losing their water of crystallization.

II. *Decomposition of Nitrate of Ammonia; Production of respirable Nitrous Oxide; its Properties.*

200 grains of compact nitrate of ammonia were introduced into a glass retort, and decomposed slowly by the heat of a spirit lamp. The first portions of the gas that came over were rejected, and the last received in jars containing mercury. No luminous appearance was perceived in the retort during the process, and almost the whole of the salt was resolved into fluid and gas. The fluid had a faint acid taste, and contained some undecomposed nitrate. The gas collected exhibited the following properties:—

a. A candle burnt in it with a brilliant flame, and crackling noise. Before its extinction, the white inner flame became surrounded with an exterior blue one.

b. Phosphorus introduced into it in a state of inflammation, burnt with infinitely greater vividness than before.

c. Sulphur introduced into it when burning with a feeble blue flame, was instantly extinguished; but when in a state of active inflammation (that is, forming sulphuric acid)* it burnt with a beautiful and vivid rose-coloured flame.

d. Inflamed charcoal, deprived of hydrogen, introduced into it, burnt with much greater vividness than in the atmosphere.

e. To some fine twisted iron wire a small piece of cork was affixed: this was inflamed, and the whole introduced into a jar of the air. The iron burned with great vividness, and threw out bright sparks as in oxygen.

f. 30 measures of it exposed to water previously boiled, was rapidly absorbed; when the diminution was complete, rather more than a measure remained.

g. Pure water saturated with it, gave it out again on ebullition, and the gas thus produced retained all its former properties.

* [When the above was written, the rationale of the formation of sulphuric acid was not known; the author discovered it later,—and how water is essential to its production,—and how nitrous gas is capable of combining with sulphureous acid gas, and when water is present, of relinquishing part of its oxygen to the sulphureous acid to form sulphuric acid. If sulphuric acid result from the vivid combustion of sulphur in nitrous oxide, it is probable that this compound of nitrous acid gas and sulphureous acid gas is first formed, and the sulphuric acid is derived from it, through the agency of moisture.—*Vide Elements of Chemical Philosophy, article Sulphur.*]

h. It was absorbed by red-cabbage juice; but no alteration of colour took place.

i. Its taste was distinctly sweet, and its odour slight, but agreeable.

j. It underwent no diminution when mingled with oxygen or nitrous gas.

Such were the obvious properties of the Nitrous Oxide, or the gas produced by the decomposition of nitrate of ammonia in a temperature not exceeding 440° . Other properties of it will be hereafter demonstrated, and its affinities fully investigated.

III. *Of the Gas remaining after the Absorption of Nitrous Oxide by Water.*

In exposing nitrous oxide at different times to rain or spring water, and water that had been lately boiled, I found that the gas remaining after the absorption was always least when boiled water was employed, though from the mode of production of the nitrous oxide, I had reason to believe that its composition was generally the same.

This circumstance induced me to suppose that some of the residuum might be gas previously contained in the water, and liberated from it in consequence of the stronger affinity of that fluid for nitrous oxide. But the greater part of it I conjectured to consist of nitrogen, produced in consequence of a complete decomposition of part of the acid by the hydrogen. It was in endeavouring to ascertain the relative purity of nitrous oxide produced at different periods of the process of the decomposition of nitrate of ammonia, that I discovered the true reason of the appearance of residual gas.

I decomposed some pure nitrate of ammonia in a small glass retort; and after suffering the first portions to escape with the common air, I caught the remainder in three separate vessels standing in the same trough, filled with water that had been long boiled, and which at the time of the experiment was so warm that I could scarcely bear my hands in it. The different quantities collected gave the same intense brilliancy to the flame of a taper.

26 measures of each of them were separately inserted into 3 graduated cylinders, of nearly the same capacity, over the same boiled water. As the water cooled, the gas was absorbed by agitation. When the diminution was complete, the residuum in each cylinder filled, as nearly as possible, the same space; about two-thirds of a measure.

To each of the residuums I added two measures of nitrous gas; they gave copious red vapour, and after the condensation filled a space rather less than two measures.

Hence the residual gas contained more oxygen than common air.

I now introduced 26 measures of gas from one of the vessels into a cylinder filled with unboiled spring water of the same kind.* After the absorption was complete, nearly two measures remained. These added to two measures of nitrous air, diminished to 2·5 nearly.

These experiments induced me to believe that the residual gas was not produced in the decomposition of nitrate of ammonia, but that it was wholly liberated from the water.

* Two measures of air dispelled from this water by boiling, mingled with 2 of nitrous gas, diminished to 2·4 nearly.

To ascertain this point with precision, I distilled a small quantity of the same kind of water, which had been near an hour in ebullition, into a graduated cylinder containing mercury. To this I introduced about one-third of its bulk, *i. e.* 12 measures of nitrous oxide, which had been carefully generated in the mercurial apparatus. After the absorption, a small globule of gas only remained, which could hardly have equalled one-fourth of a measure. On admitting to this globule a minute quantity of nitrous gas, an evident diminution took place.

Though this experiment proved that in proportion as the water was free from air, the residuum was less, and though there was no reason to suppose that the ebullition and distillation had freed the water from the whole of the air it had held in solution, still I considered a decisive experiment wanting to determine whether nitrous oxide was the only gas produced in the slow decomposition of nitrate of ammonia, or whether a minute quantity of oxygen was not likewise evolved.

I received the middle part of the product of a decomposition of nitrate of ammonia, under a cylinder filled with dry mercury, and introduced to it some strong solution of ammonia. After the white cloud produced by the combination of the ammoniacal vapour with the nitric acid suspended in the nitrous oxide, had been completely precipitated, I introduced a small quantity of nitrous gas. No white vapour was produced.

Now if any gas combinable with nitrous gas had existed in the cylinder, the quantity of nitrous acid produced, however small, would have been rendered perceptible by the ammoniacal fumes; for when a

minute globule of common air was admitted into the cylinder, white clouds were instantly perceptible.

It seems therefore reasonable to conclude,

1. That the residual gas of nitrous oxide, is air previously contained in the water, (which in no case can be perfectly freed from it by ebullition,) and liberated by the stronger attraction of that fluid for nitrous oxide.

2. That nitrate of ammonia, at temperatures below 440° , is decomposed into pure nitrous oxide, and fluid.

3. That in ascertaining the purity of nitrous oxide from its absorption by water, corrections ought to be made for the quantity of gas dispelled from the water. This quantity in common water distilled under mercury being about $\frac{1}{36}$; in water simply boiled, and used when hot, about $\frac{1}{36}$; and in common spring water, $\frac{1}{12}$.

IV. *Specific Gravity of Nitrous Oxide.*

To understand accurately the changes taking place during the decomposition of nitrate of ammonia, we must be acquainted with the specific gravity and composition of nitrous oxide.

90 cubic inches of it, containing about $\frac{1}{33}$ common air, introduced from the mercurial air-holder into an exhausted globe, increased it in weight 44.75 grains; thermometer being 51° , and atmospheric pressure 30.7.

106 cubic inches, of similar composition, weighed in like manner, gave at the same temperature and pressure nearly 52.25 grains; and in another experiment, when the thermometer was 41° , 53 grains.

So that accounting for the small quantity of common air contained in the gases weighed, we may conclude,

that 100 cubic inches of pure nitrous oxide weigh 50·1 grains at temperature 50°, and atmospheric pressure 30·7.

I was a little surprised at this great specific gravity, particularly as I had expected, from Dr. Priestley's observations, to find it less heavy than atmospherical air. This philosopher supposed, from some appearances produced by the mixture of it with aëiform ammonia, that it was even of less specific gravity than that gas.*

V. *Analysis of Nitrous Oxide.*

The nitrous oxide may be analyzed, either by charcoal or hydrogen; during the combustion of other bodies in it, small portions of nitrous acid are generally formed, as will be fully explained hereafter.

The gas that I employed was generated from compact nitrate of ammonia, and was in its highest state of purity, as it left a residuum of $\frac{1}{38}$ only, when absorbed by boiled water.

10 cubic inches of it were inserted into a jar graduated to ·1 cubic inch, containing dry mercury. Through this mercury a piece of charcoal which had been deprived of its hydrogen by long exposure to heat, weighing about a grain, was introduced, while yet warm. No perceptible absorption of the gas took place.†

Thermometer being 46°, the focus of a lens was thrown on the charcoal, which instantly took fire, and burnt vividly for about a minute, the gas being in-

* Experiments and Observations, vol. ii. page 89.

† A minute quantity, however, must have been absorbed, and given out again when the charcoal was heated.

creased in volume. After the vivid combustion had ceased, the focus was again thrown on the charcoal; it continued to burn for near ten minutes, when the process stopped.

The gas, when the original pressure and temperature were restored, filled a space equal to 12·5 cubic inches.

On introducing to it a small quantity of strong solution of ammonia,* white vapour was instantly perceived, and after a short time the reduction was to about 10·1 cubic inches; so that apparently, 2·4 cubic inches of carbonic acid had been formed. The 10·1 cubic inches of gas remaining were exposed to water which had been long in ebullition, and which was introduced whilst boiling, under mercury. After the absorption of the nitrous oxide by the water, the gas remaining was equal to 5·3.

But on combining a cubic inch of pure nitrous oxide with some of the same water, which had been received under mercury in a separate vessel, nearly $\frac{1}{2}$ remained. Consequently we may conclude, that 5·1 of a gas unabsorbable by water, was produced in the combustion.

This gas extinguished flame, gave no diminution with oxygen, and the slightest possible with nitrous gas. When an electric spark was passed through it, mingled with oxygen, no inflammation or *perceptible* diminution took place.† We may consequently conclude that it was nitrogen, mingled with a minute portion of common air, expelled from the water.

The charcoal was diminished in bulk to one-half nearly, but the loss of weight could not be ascertained, as its pores were filled with mercury.

* Strong solution of ammonia has no attraction for nitrous oxide.

† The gas was examined by those tests in order to prove that no water had been decomposed.

Now 5 cubic inches of nitrous oxide were absorbed by the water, consequently 5 were decomposed by the charcoal; and these produced 5.1 cubic inches of nitrogen; and by giving their oxygen to the charcoal, apparently 2.4 of carbonic acid.

But 5 cubic inches of nitrous oxide weigh 2.5 grains, and 5.1 cubic inches of nitrogen 1.55; then $2.5 - 1.55 = .95$.

So that reasoning from the relative specific gravities of nitrogen and nitrous oxide, 2.5 grains of the last are composed of 1.55 nitrogen, and .95 oxygen.

But from many experiments made on the specific gravity of carbonic acid, in August, 1799, I concluded that 100 cubic inches of it weighed 47.5 grains, thermometer being 60.1° , and barometer 29.5. Consequently, making the necessary corrections, 2.4 cubic inches of it weigh 1.14 grains; and on Lavoisier's and Guyton's* estimation of its composition, these 1.13 grains contain 8.2 of oxygen.

So that, drawing conclusions from the quantity of carbonic acid formed in this experiment, 2.5 grains of nitrous oxide will be composed of .82 oxygen, and 1.68 nitrogen.

The difference between these estimations is considerable, and yet not more than might have been expected, if we consider the probable sources of error in the experiment.

1. It is likely that variable minute quantities of hydrogen remain combined with charcoal, even after it has been long exposed to a red heat.

2. It is probable that the nitrogen and carbonic acid

* See the curious paper of this excellent philosopher, on the combustion of the diamond, in which he proves that charcoal is, in fact, oxide of diamond. *Annales de Chimie*, xxxi.

produced were capable of dissolving more water than that held in solution by the nitrous oxide; and if so, they were more condensed than if saturated with moisture, and hence the quantity of carbonic acid under-rated.

We may consequently suppose the estimation founded on the quantity of nitrogen evolved, most correct; and making a small allowance for the difference, conclude, that 100 grains of nitrous oxide are composed of 37 oxygen, and 63 nitrogen; existing in a much more condensed state than when in their simple forms.

The tolerable accuracy of this statement will be hereafter demonstrated by a number of experiments on the combustion of different bodies in nitrous oxide, detailed in Research II.

VI. *Minute Examination of the Decomposition of Nitrate of Ammonia.*

Into a retort weighing 413·75 grains, and of the capacity of 7·5 cubic inches, 100 grains of pulverised compact nitrate of ammonia were introduced. To the neck of this retort was adapted a recipient, weighing 711 grains, tubulated for the purpose of communicating with the mercurial air-holder, and of the capacity of 8·3 cubic inches.

Temperature being 50°, and atmospheric pressure 30·6, the recipient was inserted into a vessel of cold water, and made to communicate with the air-holder. The heat of a spirit lamp was then slowly applied to the retort: the salt quickly began to decompose, and to liquefy. The temperature was so regulated, as to keep up an equable and slow decomposition.

During this decomposition, no luminous appearance

was perceived in the retort; the gas that came into the air-holder was very little clouded, and much water condensed in the receiver.

After the process was finished, the communication between the mercurial air-holder and the recipient was preserved till the common temperature was restored to the retort.

The volume of the gas in the cylinder was 85·5 cubic inches. The absolute quantity of nitrous oxide in those 85·5 cubic inches, it was difficult to ascertain with great nicety, on account of the common air previously contained in the vessels.

45 measures of it, exposed to well-boiled water, diminished by agitation to 8 measures. So that reasoning from the quantity of air, which should have been expelled from the water by the nitrous oxide, we may conclude that the 85·5 cubic inches were nearly pure.

The retort now weighed 419·25 grains, consequently 5·5 grains of salt remained in it. This salt was chiefly collected about the lower part of the neck, and contained rather more water than the compact nitrate, as in some places it was crystallized.

The recipient, with the fluid it contained, weighed 759 grains. It had consequently gained in weight 48 grains.

Now the 85·5 cubic inches of nitrous oxide produced, weigh about 42·5 grains; and this added to 48 and 5·5=96 grains; so that about 4 grains of salt and fluid were lost, probably by being carried over and deposited by the gas.*

* This was actually the case; for on examining the conducting tube the day after the experiment, some minute crystals of prismatic nitrate of ammonia were perceived in it.

As much of the fluid as could be taken out of the recipient weighed 46 grains, and held in solution much nitrate of ammonia with superabundance of acid. This acid required for its saturation, $3\frac{1}{2}$ of carbonate of ammonia (containing, as well as I could guess,) about 20 per cent. alkali.

The whole solution evaporated, gave 18 grains of compact nitrate of ammonia. But reasoning from the quantity of carbonate of ammonia employed, the free nitric acid was equal to 2.75 grains, and this must have formed 3.56 grains of salt. Consequently the salt pre-existing in the solution was about 14.44 grains.

But besides the fluid taken out of the recipient, 2 grains remained in it: let us suppose this, and the 4 grains lost, to contain 2 of salt, and .6 of free acid.

Then the undecomposed salt is

5.5 + 14.4 + 2	.	.	=	21.9
The free acid 2.75 + .6	.	.	=	3.35
Gas	.	.	.	42.5
Water	.	.	.	32.25

100

Now about 78.1 grains of salt were decomposed, and formed into 42.5 grains of gas, 3.35 grains acid, and 32.25 grains water.

But there is every reason to suppose, that in this process, when the hydrogen of the ammonia combines with a portion of the oxygen of the nitric acid to form water, and the nitrogen enters into union with the nitrogen and remaining oxygen of the nitric acid, to form nitrous oxide; that water pre-existing in nitric acid and ammonia, such as they existed in the aëriform state, is deposited with the water produced by the new

arrangement, and not wholly combined with the nitrous oxide formed. Hence it is impossible to determine with great exactness, the quantity of water, which was absolutely formed in this experiment.

78.1 grains of salt are composed of 15.4 alkali, 58 acid, and 4.7 water.

And reasoning from the different affinities of water for nitric acid, ammonia, and nitrous oxide, it is probable that ammonia, in its decomposition, divides its water in such a ratio, between the nitrogen furnished to the nitrous oxide, and the hydrogen entering into union with the oxygen of the nitric acid, as to enable us to assume, that the hydrogen requires for its saturation nearly the same quantity of oxygen as when in the aëriform state; or that it certainly cannot require less.

But 15.4 alkali contain 3.08 hydrogen, and 12.32 nitrogen; * and 3.08 hydrogen require 17.4 of oxygen to form 20.48 of water.

Now 32.5 grains of water existed before the experiment; 4.7 grains of water were contained by the salt decomposed, and $32.5 - 4.7 = 27.8$: and $27.8 - 20.48$, the quantity generated, = 7.52, the quantity existing in the nitric acid.

But the nitric acid decomposed is $58^* - 3.35 =$ to 54.7; and $54.7 - 7.5 = 47.2$, which entered into new combinations. These 47.2 consist of 33.2 oxygen, and 14, nitrogen. And $33.2 - 17.4$, the quantity employed to form the water, = 15.8, which combined with 14, nitrogen of the nitric acid, and 12.32 of that of the ammonia, to form 42.12 of nitrous oxide. And on this estimation, 100 parts of nitrous oxide would contain 37.6 oxygen, and 62.4 nitrogen; a computation much

* Owing part of their weight to an unknown quantity of water.

nearer the results of the analysis than could have been expected, particularly as so many unavoidable sources of error existed in the process.

The experiment that I have detailed is the most accurate of four, made on the same quantity of salt. The others were carried on at rather higher temperatures, in consequence of which, more water and salt were sublimed with the gas.

To Berthollet, we owe the discovery of the products evolved during the slow decomposition of nitrate of ammonia; but as this philosopher, in his examination of this process, chiefly designed to prove the existence of hydrogen in ammonia, he did not ascertain the quantity of gas produced, or minutely examine its properties; from two of them, its absorption by water and its capability of supporting the vivid combustion of a taper, he inferred its identity with the dephlogisticated nitrous gas of Priestley, and concluded that it was nitrous gas with excess of pure air.*

VII. *Of the Heat produced during the Decomposition of Nitrate of Ammonia.*

To ascertain whether the temperature of nitrate of ammonia was increased or diminished after it had been raised to the point essential to its decomposition, during the evolution of nitrous oxide and water; that is, in common language, whether heat was generated or absorbed in the process; I introduced a thermometer into about 1500 grains of fibrous nitrate of ammonia, rendered liquid in a deep porcelain cup. During the whole of the evaporation, the temperature was about 380°, the fire being carefully regulated.

* Mem. de Paris, 1785, and Journal de Physique, 1786, page 175.

As soon as the decomposition took place, the thermometer began to rise; in less than a quarter of a minute it was 410° , in two minutes it was 460° .

The cup was removed from the fire; the decomposition still went on rapidly, and for about a minute the thermometer was stationary. It then gradually and slowly fell; in three minutes it was 440° , in five minutes 420° , in seven minutes 405° , in nine minutes 360° , and in thirteen minutes 307° , when the decomposition had nearly ceased, and the salt began to solidify.

From this experiment, it is evident that an increase of temperature is produced by the decomposition of nitrate of ammonia: though the capacity of water and nitrous oxide for heat, supposing the truth of the common doctrine, and reasoning from analogy, must be considerably greater than that of the salt.

VIII. *Of the Decomposition of Nitrate of Ammonia at high Temperatures, and Production of Nitrous Gas, Nitrogen, Nitrous Acid, and Water.*

At an early period of my investigation relating to the nitrous oxide, I discovered that when a heat above 600° was applied to a nitrate of ammonia, so that a vivid luminous appearance was produced in the retort, certain portions of nitrous gas, and nitrogen, were evolved with the nitrous oxide. But I was for some time ignorant of the precise nature of this decomposition, and doubtful with regard to the possibility of effecting it in such a manner as to prevent the production of nitrous oxide altogether.

I first attempted to decompose nitrate of ammonia at high temperatures, by introducing it into a well-coated

green glass retort, having a wide neck, communicating with the pneumatic apparatus, and strongly heated in an air-furnace. But though in this process a detonation always took place, and much light was produced, yet still the greater portion of the gas generated was nitrous oxide; the nitrous gas and nitrogen never amounting to more than one-third of the whole.

After breaking many retorts by explosions, without gaining any accurate results, I employed a porcelain tube, curved so as to be capable of introduction into the pneumatic apparatus, and closed at one end.

The closed end was heated red, nitrate of ammonia introduced into it, and all the latter portions of gas produced in the explosion, received in the pneumatic apparatus, filled with warm water.

Three explosions were required to fill a jar of the capacity of 20 cubic inches. The gas produced in the first, when it came over, was transparent and dark orange, similar in its appearance to the nitrous acid gas produced in the first experiment; but it speedily became white and clouded, whilst a slight diminution of volume took place.

When the second portion was generated and mingled with the clouded gas, it again became transparent and yellow for a short time, and then assumed the same appearance as before.

The water in the trough, after this experiment, had an acid taste, and quickly reddened cabbage juice rendered green by an alkali.

Six cubic inches of the gas produced were exposed to boiled water, but little or no absorption took place. Hence, evidently, it contained no nitrous oxide.

They were then exposed to solution of sulphate of

iron : the solution quickly became dark coloured, and an absorption of 1·6 took place on agitation.*

The gas remaining instantly extinguished the taper, and was consequently nitrogen.

This experiment was repeated, with nearly the same results.

We may then conclude, that at high temperatures, nitrate of ammonia is wholly resolved into water, nitrous acid, nitrous gas, and nitrogen ; whilst a vivid luminous appearance is produced.

The transparency and orange colour produced in the gas that had been clouded, by new portions of it, doubtless arose from the solution of the nitric acid and water forming the cloud, in the heated nitrous vapour produced, so as to constitute an aëriform triple compound ; whilst the cloudiness and absorption subsequent were produced by the diminished temperature, which destroyed the ternary combination, and separated the nitrous acid and water from the nitrous gas.

From the rapidity with which the deflagration of nitrate of ammonia proceeds, and from the immense quantity of light produced, it is reasonable to suppose that a very great increase of temperature takes place. The tube in which the decomposition has been effected, is always ignited after the process.

IX. *Speculations on the Decompositions of Nitrate of Ammonia.*

All the phenomena of chemistry concur in proving, that the affinity of one body, A, for another, B, is not destroyed by its combination with a third, C, but only

* The absorption of nitrous gas by sulphate of iron, &c. will be treated of in the next Division.

modified; either by condensation, or expansion, or by the attraction of C for B.

On this principle, the attraction of compound bodies for each other must be revolved into the reciprocal attractions of their constituents, and consequently the changes produced in them by variations of temperature explained, from the alterations produced in the attractions of those constituents.

Thus in nitrate of ammonia, four affinities may be supposed to exist:

1. That of hydrogen for nitrogen, producing ammonia.
2. That of oxygen for nitrous gas, producing nitric acid.
3. That of the hydrogen of ammonia for the oxygen of nitric acid.
4. That of the nitrogen of ammonia for the nitrous gas of nitric acid.

At temperatures below 300° , the salt, from the equilibrium between these affinities, preserves its existence.

Now when its temperature is raised to 400° , the attractions of hydrogen for nitrogen,* and of nitrous gas for oxygen,† are diminished; whilst the attraction of hydrogen for oxygen‡ is increased; and perhaps that of nitrogen for nitrous gas.

Hence the former equilibrium of affinity is destroyed, and a new one produced.

The hydrogen of the ammonia combines with the oxygen of the nitric acid to generate water; and the

* As is evident from the decomposition of ammonia by heat.

† Nitric acid is phlogisticated by heat, as appears from Priestley's experiments, vol. iii. p. 26.

‡ As is evident from the increase of temperature required for the formation of water.

nitrogen of the ammonia enters into combination with the nitrous gas to form nitrous oxide: and the water and nitrous oxide produced, most probably exist in binary combination in the aëriform state, at the temperature of the decomposition.

But when a heat above 800° is applied to nitrate of ammonia, the attractions of nitrogen and hydrogen for each other, and of oxygen for nitrous gas,* are still more diminished; whilst that of nitrogen for nitrous gas is destroyed, and that of hydrogen for oxygen increased to a great extent: likewise a new attraction takes place; that of nitrous gas for nitric acid, to form nitrous vapor.† Hence a new arrangement of principles is rapidly produced; the nitrogen of ammonia having no affinity for any of the single principles at this temperature, enters into no binary compound: the oxygen of the nitric acid forms water with the hydrogen, and the nitrous gas combines with the nitric acid to form nitrous vapor. All these substances most probably exist in combination at the temperature of their production;

* For ammonia and nitrous oxide are both decomposed at the red heat, and oxygen given out from nitric acid when it is passed through a heated tube.

† Whenever nitrous acid is produced at high temperatures, it is always highly phlogisticated, provided it has not been long in contact with oxygen. When Dr. Priestley passed nitric acid through a tube heated red, he procured much oxygen and phlogisticated acid; and the water in the apparatus employed was fully impregnated with nitrous air. Hence it would appear, that heat diminishes the attraction between oxygen and nitrous gas, and increases the affinity of nitrous gas for nitrous acid. Mr. James Thomson, whose theory of the nitrous acid I have already mentioned, from some experiments on the phlogistication of nitric acid by heat, which he has communicated to me, concludes with great justness, that a portion of the acid is always completely decomposed in this process: the oxygen liberated, and the nitrous gas combined with the remaining acid.

and at a lower temperature, assume the forms of nitrous acid, nitrous gas, nitrogen, and water.

I have avoided entering into any discussions concerning the light and heat produced in this process; because these phenomena cannot be reasoned upon as isolated facts, and their relation to general theory will be treated of hereafter.

X. On the Preparation of Nitrous Oxide for Experiments on Respiration.

When compact nitrate of ammonia is slowly decomposed, the nitrous oxide produced is almost immediately fit for respiration; but as one part of the salt begins to decompose before the other is rendered fluid, a considerable loss is produced by sublimation.

For the production of large quantities of nitrous oxide, fibrous nitrate of ammonia should be employed. This salt undergoes no decomposition till the greater part of its water is evaporated, and in consequence at the commencement of that process, is uniformly heated.

The gas produced from fibrous nitrate, must be suffered to rest at least for an hour after its generation. At the end of this time it is generally fit for respiration. If examined before, it will be found to contain more or less of a white vapor, which has a disagreeable acidulous taste, and strongly irritates the fauces and lungs. This vapor, most probably, consists of acid nitrate of ammonia and water, which were dissolved by the gas at the temperature of its production, and afterwards slowly precipitated,

It is found in less quantity when compact nitrate is employed, because more salt is sublimed in this process,

which being rapidly precipitated, carries with it the acid and water.

Whatever salt is employed, the last portions of gas produced, generally contain less vapour, and may in consequence be respired sooner than the first.

The nitrate of ammonia should never be decomposed in a metallic vessel,* nor the gas produced suffered to come in contact with any metallic surface; for in this case the free nitric acid will be decomposed, and in consequence, a certain quantity of nitrous gas produced.

The apparatus that has been generally employed in the medical pneumatic institution, for the production of nitrous oxide, consists of

1. A glass retort, of the capacity of two or three quarts, orificed at the top, and furnished with a ground stopper.

2. A glass tube, conical for the purpose of receiving the neck of the retort; about $\frac{1}{4}$ inch wide in the narrowest part, 4 feet long, curved at the extremity, so as to be capable of introduction into an air-holder, and inclosed by tin plate to preserve it from injury.

3. Air-holders of Mr. Watt's invention, filled with water saturated with nitrous oxide.

4. A common air-furnace, provided with dampers for the regulation of the heat.

The retort, after the insertion of the salt, is connected with the tube, carefully luted, and exposed to the heat of the furnace, on a convenient stand. The temperature is never suffered to be above 500° . After the decomposition has proceeded for about a minute, so that the gas evolved from the tube enlarges the flame of a taper, the curved end is inserted into the air-holder, and the nitrous oxide preserved.

* Except it be gold or platina.

The water thrown out of the air-holders in consequence of the introduction of the gas, is preserved in a vessel adapted for the purpose, and employed to fill them again: for if common water were employed in every experiment, a great loss of gas would be produced from absorption.

A pound of fibrous nitrate of ammonia, decomposed at a heat not above 500° , produces nearly 5 cubic feet of gas; whilst from a pound of compact nitrate of ammonia, rarely more than 4.25 cubic feet can be collected.

For the production of nitrous oxide in quantities not exceeding 20 quarts, a mode still more simple than that I have just described may be employed. The salt may be decomposed by the heat of an argand lamp, or a common fire, in a tubulated glass retort, of 20 or 30 cubic inches in capacity, furnished with a long neck, curved at the extremity; and the gas received in small air-holders.

Thus, if the pleasurable effects, or medical properties of the nitrous oxide, should ever make it an article of general request, it may be procured with much less time, labour, and expense,* than most of the luxuries, or even necessities, of life.

DIVISION IV.

EXPERIMENTS AND OBSERVATIONS ON THE COMPOSITION OF NITROUS GAS, AND ON ITS ABSORPTION BY DIFFERENT BODIES.

I. *Preliminaries.*

In my account of the composition of nitric acid, in

* A pound of nitrate of ammonia costs about 5s. 10d. This pound, properly decomposed, produces rather more than 34 moderate doses of

Division I. I gave an estimation of the quantities of oxygen and nitrogen combined in nitrous gas: I shall now detail the experiments on which that estimation is founded.

At an early period of my researches relating to nitrous oxide, from the observation of the phenomena taking place during the production of this substance, I had concluded, that the common opinion with regard to the composition of nitrous gas, was very distant from the truth. I had indeed analysed nitrous gas, by converting it into nitrous oxide, before I attempted to ascertain its composition by immediately separating the constituent principles from each other: and my first hopes of the possibility of effecting this, were derived from Dr. Priestley's experiments on the combustion of pyrophorus in nitrous gas, and on the changes effected in it, by heated iron and charcoal.

This great philosopher found, that pyrophorus placed in contact with nitrous gas, burnt with great vividness, whilst the gas was diminished in volume to about one-half, which generally consisted of nitrogen and nitrous oxide.* He likewise found iron, heated by a lens in nitrous gas, increased in weight, whilst the gas was diminished about $\frac{1}{2}$, and converted into nitrogen.*

He heated common charcoal, and charcoal of copper,† in nitrous gas by a lens. When common charcoal was employed, the gas was neither increased or diminished in bulk, but wholly converted into nitrogen; when charcoal of copper was used, the volume was a little

air; so that the expense of a dose is about 2d. What fluid stimulus can be procured at so cheap a rate?

* Experiments and Observations, vol. ii. p. 50.

† That is, charcoal produced by the decomposition of spirits of wine, vol. ii. p. 39.

increased, and the gas remaining consisted of $\frac{1}{2}$ nitrogen, and $\frac{1}{2}$ carbonic acid,

In his experiments on the iron and pyrophorus, the nitrous gas was evidently decomposed. From the great quantity of nitrogen produced in those on the charcoal, it seems likely that both the common charcoal,* and the charcoal of copper employed contained atmospheric air, which being dispelled by the heat of the lens, was decomposed by the nitrous gas: indeed, till I made the following experiment, I suspected that the carbonic acid produced, when the charcoal of copper was employed, arose from a decomposition of the nitrous acid, formed in this way.

I introduced a piece of well-burnt charcoal, which could hardly have weighed the eighth of a grain, whilst red hot, under a cylinder filled with mercury, and admitted to it half a cubic inch of nitrous gas. A slight absorption took place.

The sun being very bright, I kept the charcoal in the focus of a small lens for near a quarter of an hour. At the end of this time the gas occupied a space nearly as before the experiment, and a very minute portion of the charcoal had been consumed. On introducing into the cylinder a small quantity of solution of strontian, a white precipitation was perceived, and the gas slowly

* Dr. Priestley says, "having heated iron in nitrous air, I proceeded to heat in the same air a piece of charcoal not long after it had been subjected to a strong heat covered with sand. The sun not shining immediately after the charcoal was introduced into the vessel of air, through the mercury by which it was confined, part of the air was absorbed; but on heating the charcoal, the quantity was increased. Having continued the progress as long as I thought necessary, I examined the air and found it to be about as much as the original quantity of nitrous air; but it was all phlogisticated air, extinguishing a candle and having no mixture of fixed air in it."—*Experiments and Observations*, vol. ii. p. 39.

diminished to about three-tenths of a cubic inch. To these three-tenths a little common air was admitted, when very slight red fumes were perceived.

This experiment convinced me, that the attraction of charcoal for the oxygen of nitrous gas, at high temperatures, was sufficiently strong to effect a slow decomposition of it.

To be more accurately acquainted with this decomposition, and to learn the quantities of carbonic acid and nitrogen produced from a known quantity of nitrous gas, I proceeded in the following manner.

II. *Analysis of Nitrous Gas by Charcoal.*

A quantity of nitrous gas was procured in a water apparatus, from the decomposition of nitrous acid by mercury. A portion of it was transferred to the mercurial trough. After the mercury and the jar had been dried by bibulous paper, 40 measures of this portion were agitated in a solution of sulphate of iron. The gas remaining after the absorption was complete, filled about a measure and half; so that the nitrous gas contained nearly $\frac{1}{28}$ nitrogen.

Thermometer being 53° , a small piece of well-burnt charcoal, the weight of which could hardly have equalled a quarter of a grain, was introduced ignited into a small cylinder filled with mercury, graduated to 10 grain measures; to this, 16 measures, equal to 160 grain measures of nitrous gas, were admitted. An absorption of about one measure and half took place. When the focus of a lens was thrown on the charcoal, a slight increase of the gas was produced, from the emission of that which had been absorbed.

After the process had been carried on for about a

half an hour, the charcoal evidently began to fume, and to consume very slowly, though no alteration in the volume of the gas was observed.

The sun not constantly shining, the progress of the experiment was now and then stopped: but taking the whole time, the focus could not have been applied to it for less than four hours. When the process was finished, the gas was increased in bulk nearly three quarters of a measure.

A drop of water was introduced into the cylinder, by means of a small glass tube, on the supposition that the carbonic acid, and nitrogen, might be capable of holding in solution more water than that contained in the nitrous gas decomposed; but no alteration of volume took place.

When 20 grain measures of solution of pale green* sulphate of iron were introduced into the cylinder, they became rather yellower than before, but not dark at the edges, as is always the case when nitrous gas is present. On agitation, a diminution of nearly half a measure was produced, doubtless from the absorption of some of the carbonic acid by the solution.

A small quantity of caustic potash, much more than was sufficient to decompose the sulphate of iron, was now introduced. A rapid diminution took place, and the gas remaining filled about 8 measures. This gas was agitated for some time over water, but no absorption took place. Two measures of it were then transferred into a detonating cylinder with two measures of oxygen. The electric spark was passed through them, but no diminution was produced. Hence it was nitrogen, mingled with no ascertainable quantity of hydrogen:

* That is, sulphate of iron containing oxide of iron, in the first degree of oxygenation.

consequently little or no water could have been decomposed in the process.

Now supposing, for the greater ease of calculation, each of the measures employed cubic inches.

16 of nitrous gas — $\frac{1}{26} = 15.4$ were decomposed, and these weigh, making the necessary corrections, 5.2; but 7.4 nitrogen were produced, and these weigh about 2.2. So that reasoning from the relative specific gravities of nitrous gas and nitrogen, 5.2 grains of nitrous gas will be composed of 3 oxygen, and 2.2 nitrogen.

But 8.7 of carbonic acid were produced, which weigh 4.1 grains, and consist of 2.9 oxygen, and 1.2 charcoal.* Consequently, drawing conclusions from the quantity of carbonic acid formed, 5.2 grains of nitrous gas will consist of 2.9 oxygen, and 2.3 nitrogen.

The difference in these estimations is much less than could have been expected; and taking the mean proportions, it would be inferred from them, that 100 grains of nitrous gas, contain 56.5 oxygen, and 43.5 nitrogen.

I repeated this experiment with results not very different, except that the increase of volume was rather greater, and that more unabsorbable gas remained; which probably depended on the decomposition of a minute quantity of water, that had adhered to the charcoal in passing through the mercury.

As nitrous gas is decomposable into nitrous acid, and nitrogen, by the electric spark, it occurred to me, that a certain quantity of nitrous acid might have been possibly produced, in the experiments on the decomposition of nitrous gas, by the intensely ignited charcoal. To ascertain this circumstance, I introduced into 12 measures of nitrous gas, a small piece of charcoal

* That is, carbon, or oxide of diamond.

which had been just reddened. The sun being very bright, the focus of the lens was kept on it for rather more than an hour and a quarter. In the middle of the process it began to fume and to sparkle, as if in combustion. In three quarters of an hour, the gas was increased rather more than half a measure; but no alteration of volume took place afterwards.

The mercury was not white on the top as is usually the case when nitrous acid is produced. On introducing into the cylinder a little pale green sulphate of iron, and then adding prussiate of potash, a white precipitate only was produced. Now, if the minutest quantity of nitric acid had been formed, it would have been decomposed by the pale green oxide of iron, and hence, a visible quantity of prussian blue* produced, as will be fully explained hereafter.

III. *Analysis of Nitrous Gas by Pyrophorus.*

I placed some newly made pyrophorus, about as much as would fill a quarter of a cubic inch, in a jar filled with dry mercury, and introduced to it four cubic inches of nitrous gas, procured from mercury and nitric acid.

It instantly took fire, and burnt with great vividness for some moments.

After the combustion had ceased, the gas was diminished about three quarters of a cubic inch. The remainder was not examined; for the diminution appeared to go on for some time after; in a half hour, when it was complete, it was to 2 cubic inches. A taper, introduced into these, burnt with an enlarged

* That is, blue prussiate of iron.

flame, blue at the edges; from whence it appeared, that they were composed of nitrogen and nitrous oxide.

I now introduced about half a cubic inch of pyrophorus to two cubic inches of nitrous gas; the combustion took place, and the gas was rapidly diminished to one-half; and on suffering it to remain five minutes, to one-third nearly; which extinguished flame.

Suspecting that this great diminution was owing to the absorption of some of the nitrogen formed, by the charcoal of the pyrophorus, I carefully made a quantity of pyrophorus; employing more than two-thirds of alum, to one-third of sugar.

To rather more than half of a cubic inch of this, 2 cubic inches of nitrous gas, which contained about $\frac{1}{40}$ nitrogen, were admitted. After the combustion, the gas remaining *apparently* filled a space equal to 1.2 cubic inches; but, as on account of the burnt pyrophorus in the jar, it was impossible to ascertain the volume with nicety, it was carefully and wholly transferred into another jar. It filled a space equal to 1.15 cubic inches nearly.

When water was admitted to this gas no absorption took place. It underwent no diminution with nitrous gas, and a taper plunged into it was instantly extinguished. We may consequently conclude that it was nitrogen.

Now 2 cubic inches of nitrous gas weigh .686 grains, and 1.1 of nitrogen—.05, the quantity previously contained in the gas = to 1.05, 3.19. Hence .686 of nitrous gas would be composed of .367 oxygen, and .319 nitrogen; and 100 grains would contain 53.4 oxygen, and 46.6 nitrogen.

IV. *Additional Observations on the Combustion of Bodies in Nitrous Gas, and on its Composition.*

Though phosphorus may be fused, and even sublimed, in nitrous gas, without producing the slightest luminous appearance,* yet it is introduced into it in a state of active inflammation, it burns with almost as much vividness as in oxygen.† Hence it is evident, that at the heat of ignition, phosphorus is capable of attracting the oxygen from the nitrogen of nitrous gas.

I attempted to analyze nitrous gas, by introducing into a known quantity of it, confined by mercury, phosphorus, in a vessel containing a minute quantity of oxygen.‡ The phosphorus was inflamed with an ignited iron wire, by which, at the moment of the combustion, the vessel containing it was raised from the mercury into the nitrous gas. But after making in this way, five or six unsuccessful experiments, I desisted. When the communication between the vessels was made before the oxygen was nearly combined with the phosphorus, nitrous acid was formed, which instantly destroyed the combustion; when, on the contrary, the phosphorus

* No luminous appearance is produced when phosphorus is introduced into *pure* nitrous gas. It has often been observed, that phosphorus is luminous in nitrous gas, that has not been long in contact with water after its production. This phenomenon, I suspect, depends either on the decomposition of the nitric acid held in solution by the nitrous gas; or on the combination of the phosphorus with oxygen loosely adhering to the binary æriform compound of nitric acid and nitric gas. I have not yet examined if nitrous gas can be converted into nitrous oxide by long exposure to heated phosphorus: it appears, however, very probable.

† Perhaps this fact has been noticed before; I have not, however, met with it in any chemical work.

‡ This mode of inflaming bodies in gases, not capable of supporting combustion at low temperatures, will be particularly described hereafter.

was suffered to consume almost the whole of the oxygen, it was not sufficiently ignited when introduced, to decompose the nitrous gas.

In one experiment, indeed, the phosphorus burnt for a moment in the nitrous gas; the diminution, however, was slight, and not more than $\frac{1}{4}$ of it was decomposed.

Sulphur, introduced in a state of vivid inflammation, into nitrous gas, was instantly extinguished.

I passed a strong electric shock through equal parts of hydrogen and nitrous gas, confined by mercury in a detonating tube; but no inflammation, or perceptible diminution, was produced.

19.2 grain measures of hydrogen were fired by the electric shock, with 10 of nitrous oxide, and 6 of nitrous gas; the diminution was to 17; and pale green sulphate of iron admitted to the residuum, was not discoloured. Consequently the nitrous gas was decomposed by the hydrogen, and as will be hereafter more clearly understood, nearly as much nitrogen furnished by it, as would have been produced from half the quantity of nitrous oxide.

Suspecting that phosphorated hydrogen might inflame with nitrous gas, I passed the electric spark through one measure of phosphorated hydrogen, and 4 of nitrous gas; but no diminution was perceptible. I likewise passed the electric spark through one of nitrous gas, with 2 of phosphorated hydrogen, without inflammation.

Perhaps if I had tried many other different proportions of the gases, I should have at last discovered one, in which they would have inflamed; for, as will be seen hereafter, nitrous oxide cannot be decomposed by

the compound combustible gases, except definite quantities are employed.

From Dr. Priestley's experiments on iron and pyrophorus, and from the experiments I have detailed, on charcoal, phosphorus, and hydrogen, it appears that at certain temperatures, nitrous gas is decomposable by most of the combustible bodies: even the extinction of sulphur, when introduced into it in a state of inflammation, depends perhaps on the smaller quantity of heat produced by the combustion of this body, than that of most others.

The analysis of nitrous gas by charcoal, as affording data for determining immediately the quantities of oxygen and nitrogen, ought to be considered as most accurate; and correcting it by mean calculations derived from the decomposition of nitrous gas by pyrophorus and hydrogen, and its conversion into nitrous oxide, a process to be described hereafter, we may conclude, that 100 grains of nitrous gas are composed of 55.95 oxygen, and 44.05 nitrogen; or taking away decimals, of 56 oxygen, and 44 nitrogen.

This estimation will agree very well with the mean proportions that would be given from Dr. Priestley's experiments on the decomposition of nitrous gas by iron; but as he never ascertained the purity of his nitrous gas,* and probably employed different kinds in different experiments, it is impossible to fix on any one, from which accurate conclusions can be drawn.

Lavoisier's estimation of the quantities of oxygen and nitrogen entering into the composition of nitrous gas, has been generally adopted. He supposes 64 parts

* Experiments and Observations, vol. ii. p. 40, 2d edit.

of nitrous gas to be composed of $43\frac{1}{2}$ of oxygen, and $20\frac{1}{2}$ of nitrogen.*

The difference between this account and mine is very great indeed; but I have already, in Division I., pointed out sources of error in the experiments of this great man, on the decomposition of nitre by charcoal; which experiments were fundamental, both to his accounts of the constitution of nitrous acid, and nitrous gas.

V. Of the Absorption of Nitrous Gas by Water.

Amongst the properties of nitrous gas noticed by its great discoverer, is that of absorbability by water.

In exposing nitrous air to distilled water, Dr. Priestley found a diminution of the volume of gas, nearly equal to one-tenth of the bulk of the water; and by boiling the water thus impregnated, he procured again a certain portion of the nitrous gas.

Humboldt, in his paper on eudiometry, mentions the diminution of nitrous gas by water. This diminution, he supposes to arise from the decomposition of a portion of the nitrous gas, by the water, and the consequent formation of nitrate of ammonia.†

* Elements, English Trans. 1st edit. pag. 216.

† He says, "On a observé, (depuis qu'on travaille sur la pureté de l'air) que le gaz nitreux, secoué avec l'eau, en souffre une diminution de volume. Quelques physiciens attribuent ce changement à une vraie absorption, à une dissolution du gaz nitreux dans l'eau; d'autres à l'air contenu dans les interstices de tous les fluides. Le cit. Vanbreda, à Delft, a fait de recherches très-exactes sur l'influence des eaux de pluie et de puit, sur les nombres eudiométriques; et les belles expériences du cit. Hassenfratz, sur l'abondance d'oxygène, contenue dans les eaux de neige et de pluie, font supposer que l'air des interstices de l'eau joue un rôle important dans l'absorption du gaz nitreux. En comparant ces effets avec les phénomènes observé dans la decomposition du sulfate de

I confess, that even before the following experiments were made, I was but little inclined to adopt this opinion: the small diminution of nitrous gas by water, and the uniform limits of this diminution, rendered it extremely improbable.

a. To ascertain the quantity of nitrous gas absorbable by pure water, and the limits of absorption, I introduced into a glass retort about 5 ounces of water, which had been previously boiled for some hours. The neck of the retort was inverted in mercury, and the water made to boil. After a third of it had been distilled, so that no air could possibly remain in the retort, the remainder was driven over, and condensed in an inverted jar filled with mercury. To three cubic inches of this water,* confined in a cylinder graduated to .05 cubic inches, 5 cubic inches of nitrous gas, containing nearly one-thirtieth nitrogen, were introduced.

After agitation for near an hour, rather more than $\frac{4}{10}$ of a cubic inch appeared to be absorbed; but though the process was continued for near two hours longer, no further diminution took place.

fer, nous supposâmes, le cit. Tassaert et moi, que le simple contact du gaz nitreux avec l'eau distillée pourroit bien causer une décomposition de ce dernier. Nous examinâmes soigneusement une petite quantité d'eau distillée, secouée avec beaucoup de gaz nitreux très-pur, et nous trouvâmes, au moyen de la terre calcaire, et l'acide muriatique, qu'il s'y forme du *nitrate d'ammoniaque*. L'eau se décompose en cette opération, par un double affinité de l'oxygene pour le gaz nitreux, et de l'hydrogene pour l'azote; il se forme de l'acide nitrique et de l'*ammoniaque*; et, quoique la quantité du dernier paroisse trop petite pour en évaluer exactement la quantité, son existence cependant se manifeste, (à ne pas sans douter) par le dégagement des vapeurs, qui blanchissent dans la proximité de l'acide muriatique. Voilà un fait bien frappant que la composition d'une substance alcaline par le contact d'une acide, et de l'eau.—*Annales de Chimie*, t. xxviii. p. 153.

* Which was certainly as free from air as it ever can be obtained.

The remaining gas was introduced into a tube graduated to $\cdot 02$ cubic inches. It measured $\frac{1}{3}\frac{4}{5}$; hence $\frac{1}{3}\frac{1}{5}$ had been absorbed.

Consequently, 100 cubic inches of pure water are capable of absorbing 11.8 of nitrous gas. In the water thus impregnated with nitrous gas I could distinguish no peculiar taste; * it did not at all alter the colour of blue cabbage juice.

b. To determine if the absorption of nitrous gas was owing to a decomposition of it by the water, as Humboldt has supposed, or to a simple solution; I procured some nitrous gas from nitrous acid and mercury, containing about one-seventieth nitrogen. $\cdot 5$ cubic inches of it, mingled with $\cdot 25$ of oxygen, from sulphuric acid and manganese, left a residuum of $\cdot 03$. 5 cubic inches more were introduced to 3 of water, procured in the same manner as in the last experiment, in the same cylinder. After the diminution was complete, the cylinder was transferred in a small vessel containing mercury, into a water bath, and nearly covered by the water.

As the bath was heated, small globules of gas were given out from the impregnated water, and when it began to boil, the production of gas was still more rapid. After an hour's ebullition, the volume of heated gas was equal to 1.4 cubic inches nearly.

The cylinder was now taken out of the bath, and quickly rendered cool by being placed in a water apparatus. At the common temperature the gas occu-

* Dr. Priestley found distilled water, saturated with nitrous air, to acquire an astringent taste and pungent smell. In some unboiled impregnated pump water, I once thought that I perceived a subacid taste; but it was extremely slight, and probably owing to nitrous acid formed by the union of the oxygen of the common air in the water, with some of the nitrous gas.

pied, as nearly as possible the space of $\cdot 5$ cubic inches: these $\cdot 5$ mingled with $\cdot 25$ of oxygene, of the same kind as that employed before, left a residuum nearly equal to $\cdot 03$.

From this experiment, which was repeated with nearly the same results, it is evident,

1. That nitrous gas is not decomposable by pure water.

2. That the diminution of volume of nitrous gas placed in contact with water, is owing to a simple solution of it in that fluid.

3. That at the temperature of 212° , nitrous gas is incapable of remaining in combination with water.

Humboldt's opinion relating to the decomposition of nitrous gas by water, is founded upon the disengagement of vapour from distilled water impregnated with nitrous gas, by means of lime, which became white in the proximity of the muriatic acid. But this is a very imperfect and fallacious test of the presence of ammonia. I have this day, April 2, 1800, heated 4 cubic inches of distilled water, impregnated with nitrous gas, with caustic lime; the vapour certainly became a little whiter when held over a vessel containing muriatic acid; but the vapour of distilled water produced precisely the same appearance,* which was owing, most

* As carbonic acid and ammonia are both products of animalisation, is it not probable that our common waters, particularly those in and near towns and cities, contain carbonate of ammonia? If so, this salt will always exist in them after distillation. In the experiments on carbonate of ammonia, to which I have often alluded, I found, in distilling a solution of this salt in water, that before half of the water had passed into the recipient, the carbonate of ammonia had sublimed; so that the distilled solution was much stronger than before, whilst the water remaining in the retort was tasteless. Will this supposition at all explain Humboldt's mistake?

likely, to the combination of the acid with the aqueous vapour. Indeed, when I added a particle of nitrate of ammonia, which might have equalled one-twentieth of a grain, to the lime and impregnated water, the increased whiteness of the vapour was but barely perceptible, though this quantity of nitrate of ammonia is much more considerable than that which could have been formed, even supposing the nitrous gas decomposed.

VI. *Of the Absorption of Nitrous Gas by Water of different Kinds.*

In agitating nitrous gas over spring water, the diminution rarely amounts to more than one-thirtieth, the volume of water being taken as unity. I at first suspected that this great difference in the quantity of gas absorbed by spring water, and pure water, depended on carbonic acid contained in the last, diminishing the attraction of it for nitrous gas: but by long boiling a quantity of spring water confined by mercury, I obtained from it one-twentieth of its bulk of air, which gave nearly the same diminution with nitrous gas, as atmospheric air.

This fact induced me to refer the difference of diminution to the decomposition of the atmospheric air held in solution by the water, the oxygen of which I supposed to be converted into nitric acid, by the nitrous gas, whilst the nitrogen was liberated; and hence the increased residuum.

a. I exposed to pure water, that is, water procured by distillation under mercury, nitrous gas, containing a known quantity of nitrogen. After the absorption was complete, I found the same quantity of nitrogen in the

residuum, as was contained in a volume of gas equal to the whole quantity employed.

b. Spring water boiled for some hours, and suffered to cool under mercury, absorbed a quantity of nitrous gas equal to one-thirteenth of its bulk; which is not much less than that absorbed by pure water.

c. I exposed to spring water, 10 measures of nitrous gas; the composition of which had been accurately ascertained; the diminution was one-twenty-eighth, the volume of water being taken as unity. On placing the residuum in contact with solution of sulphate of iron, the nitrogen remaining was nearly one-twentieth more than had been contained by the gas before its exposure to water.

d. Distilled water was saturated with common air, by being agitated for some time in the atmosphere. Nitrous gas placed in contact with this water, underwent a diminution of $\frac{1}{18}$; the volume of water being unity. The gas remaining after the absorption contained about one-twenty-seventh nitrogen more than before.

e. Nitrous gas exposed to water combined with about one-fourth of its volume of carbonic acid, diminished to $\frac{1}{3\frac{1}{2}}$ *; nearly. The remainder contained little or no superabundant nitrogen.

From these observations it appears, that the different degrees of diminution of nitrous gas by different kinds of water may depend upon various causes.

1. Less nitrous gas will be absorbed by water holding in solution earthy salts, than by pure water; and in this case the diminution of the attraction of water for nitrous gas will probably be in the ratio of the quantities of salt combined with it. *a. b.*

2. The apparent diminution of nitrous gas in water,

* The water still being unity.

holding in solution atmospheric air, will be less than in pure water, though the absolute diminution will be greater; for the same portion will be absorbed, whilst another portion is combined with the oxygen of the atmospheric air contained in the water; and from the disengagement of the nitrogen of this air, arises an increased residuum. *c. d.*

3. Probably in waters containing nitrogen, hydrogen, and other gases, absorbable only to a slight extent, the apparent diminution will be less, on account of the disengagement of those gases from the water, by the stronger affinity of nitrous gas for that fluid.

4. In water containing carbonic acid, and probably some other acid gases, the diminution will be small in proportion to the quantity of gas contained in the water: the affinity of this fluid for nitrous gas being diminished by its greater affinity for the substance combined with it. *e.*

The different diminution of nitrous gas when agitated in different kinds of water, has been long observed by experimenters on the constituent parts of the atmosphere, and various solutions have been given of the phenomenon; the most singular is that of Humboldt.* He supposes that the apparent diminution of nitrous gas is less in spring water than distilled water,

* He says, " 100 parties de gaz nitreux, (à 0.14 d'azote) secouées avec l'eau distillée, récemment cuite, diminuent en volume de 0.11, ou 0.12. Ce même gaz, en contact avec l'eau de puits, ne perd que 0.02. La cause de cette différence de 0.9, ou 0.10 ne doit pas être attribuée ni à l'impureté de l'air atmosphérique, contenu dans les interstices de l'eau, ni à la décomposition de cette eau même. Elle n'est qu'apparante; car l'acide nitrique, qui se forme par le contact du gaz nitreux avec l'eau de puits, en décompose le carbonate de chaux. Il se dégage de l'acide carbonique, qui, en augmentant le volume du residu, rend l'absorption du gaz nitreux moins sensible. Pour déterminer la quantité de cet acide

on account of the decomposition of the carbonate of lime contained in the spring water, by the nitrous acid formed from the contact of nitrous gas with the water; the carbonic acid disengaged from this decomposition increasing the residuum.

This opinion may be confuted without even reference to my observations. It is, indeed, altogether unworthy of a philosopher, generally acute and ingenious. He seems to have forgotten that carbonic acid is absorbable by water.

VII. *Of the Absorption of Nitrous Gas by Solution of pale green Sulphate of Iron.*

a. The discovery of the exact difference between the sulphates of iron, is owing to Proust.* According to the ingenious researches of this chemist, there exist two varieties of sulphate of iron, the green and the red. The oxide in the green sulphate contains $\frac{2}{100}$ oxygen. This salt, when pure, is insoluble in spirit of wine; its solution in water is of a pale green colour; it is not altered by the gallic acid, and affords a white precipitate with alkaline prussiates.

The red sulphate of iron is soluble in alcohol and uncrystallizable; its oxide contains $\frac{4.8}{100}$ oxygen. It forms a black precipitate with the gallic acid, and with the alkaline prussiates, a blue one.

The common sulphates of iron generally consist of

carbonique, je lavai le résidu avec de l'eau de chaux. Dans un grand nombre d'expériences, le volume diminua de 0.09, ou 0.07. Il faut en conclure que l'eau de puits absorbe réellement 9 + 2, ou 7 + 2 parties de gas nitreux, c'est-à-dire, à peu-près la même quantité que l'eau distillée." *Annales de Chimie*, xxviii. page 154.

* Nicholson's Phil. Jour. 4to. No. 1, page 453.

combinations of these two varieties in different proportions.

The green sulphate may be converted into the red by oxygenated muriatic acid or nitric acid. The common sulphate may be converted into green sulphate, by agitation in contact with sulphurated hydrogen.

The green sulphate has a strong affinity for oxygen, it attracts it from the atmosphere, from oxygenated marine acid, and nitric acid. The alkalies precipitate from it a pale green oxide, which, if exposed to the atmosphere, rapidly becomes yellow red.

The red sulphate of iron has no affinity for oxygen, and when decomposed by the alkalies, gives a red precipitate, which undergoes no alteration when exposed to the atmosphere.*

b. The absorption of nitrous gas by a solution of sulphate of iron, was long ago discovered by Priestley. During this absorption, he remarked a change of colour in the solution, analogous to that produced by the mixture of it with nitric acid.

This chemical fact has been lately applied by Humboldt, to the discovery of the nitrogen generally mingled with nitrous gas.

Vauquelin and Humboldt have published a memoir, on the causes of the absorption† of nitrous gas by solution of sulphate of iron. They saturated an ounce and a half of sulphate of iron in solution, with 180 cubic inches of nitrous gas.

Thus impregnated it strongly reddened tincture of turnsoyle; when mingled with sulphuric acid, gave

* I have been able to make these observations on the sulphates of iron, most of them after Proust.

† Annales de Chimie, vol. xxviii. p. 182.

nitric acid vapor; and saturated with potash, ammoniacal vapor.

By analysis, it produced as much ammonia as that contained in 4 grains of ammoniacal muriate, and a quantity of nitric acid equal to that existing in 17 grains of nitre. Hence they concluded, that the nitrous gas and a portion of the water of the solution, had mutually decomposed each other; the oxygen of the water combining with the oxygen and a portion of the nitrogen of nitrous gas to form nitric acid; and its hydrogen uniting with the remaining nitrogen, to generate ammonia.

They have taken no notice of the nature of the sulphate of iron employed, which was most probably the common or mixed sulphate; nor of the attraction of the oxide of iron in this substance for oxygen.

c. Before I was acquainted with the observations of Proust, the common facts relating to the oxygenation of vitriol of iron induced me to suppose, that the attraction of this substance for oxygen was in some way connected with the process of absorption. The comparison of the experiments of Humboldt and Vauquelin, with the observations of Proust, enabled me to discover the true nature of the process.

I procured a solution of red sulphate of iron, by passing oxygenated muriatic acid through a solution of common sulphate of iron, till it gave only a red precipitate, when mingled with caustic potash. To nitrous gas confined by mercury, a small quantity of this solution was introduced. On agitation, its colour altered to muddy green; but the absorption that took place was extremely trifling: in half an hour it did not amount to $\cdot 2$, the volume of the solution being unity, when it had nearly regained the yellow colour.

I now obtained a solution of green sulphate of iron, by dissolving iron filings in diluted sulphuric acid. The solution was agitated in contact with sulphurated hydrogen, and afterwards boiled; when it gave a white precipitate with prussiate of potash.

A small quantity of this solution agitated in nitrous gas, quickly became of an olive brown, and the gas was diminished with great rapidity; in two minutes, a quantity equal to four times the volume of the solution had been absorbed.

These facts convinced me that the solubility of nitrous gas in common sulphate of iron, chiefly depended upon the pale green sulphate contained in it; and that the attraction of one of the constituents of this substance, the green oxide of iron, for oxygen, was one of the causes of the phenomenon.

d. Green sulphate of iron rapidly decomposes nitric acid. It was consequently difficult to conceive how any affinities existing between nitrous gas, water, and green sulphate of iron, could produce the nitric acid found in the experiments of Vauquelin and Humboldt.

To ascertain if the presence of a great quantity of water destroyed the power of green sulphate of iron, to decompose nitric acid, I introduced into a cubic inch of solution of green sulphate of iron, two drops of concentrated nitric acid.

The solution assumed a very light olive colour; prussiate of potash mingled with a little of it, gave a dark green precipitate. Hence the nitric acid had been evidently decomposed. As no nitrous gas was given out, which is always the case when nitric acid is poured on crystallized sulphate of iron, I suspected that a complete decomposition of the acid had taken place; but when the solution was heated, a few minute globules of

gas were liberated, and it gradually became slightly clouded.

Having often remarked that no precipitation is ever produced during the conversion of green sulphate of iron into red, by oxygenated muriatic acid, or concentrated nitric acid, I could refer the cloudiness to no other cause than to the formation of ammonia.

To ascertain if this substance had been produced, a quantity of slacked caustic lime was thrown into the solution. On the application of heat, the ammoniacal smell was distinctly perceptible, and the vapor held over orange nitrous acid, gave dense white fumes.

e. When I considered this fact of the decomposition of nitric acid and water by the solution of green sulphate of iron, and the change of colour effected in it by the absorption of nitrous gas, exactly analogous to that produced by the decomposition of nitric acid; I was induced to believe that the nitric acid found in the analysis of Vauquelin and Humboldt, had been formed by the combination of some of the nitrous gas thrown into the solution with the oxygen of the atmosphere: and that the absorbability of nitrous gas, by solution of green sulphate of iron, was owing to a decomposition produced by the combination of its oxygen with the green oxide of iron, and of its nitrogen with the hydrogen disengaged from water, decomposed at the same time.

To ascertain this, I procured a quantity of nitrous gas: it was suffered to remain in contact with water for some hours after its production. Transferred to the mercurial apparatus, it gave no white vapor when placed in contact with solution of ammonia; and consequently held no nitric acid in solution.

Into a graduated jar filled with mercury, a cubic inch

of concentrated solution of pure green sulphate of iron was introduced, and 7 cubic inches of nitrous gas admitted to it. The solution immediately became dark olive at the edges, and on agitation this colour was diffused through it. In 3 minutes, when near $5\frac{3}{4}$ cubic inches had been absorbed, the diminution ceased. The solution was now of a bright olive brown, and transparent at the edges. After it had rested for a quarter of an hour, no farther absorption was observed; the colour was the same, and no precipitation could be perceived. A little of it was thrown into a small glass tube, under the mercury, and examined in the atmosphere. Its taste was rather more astringent than that of solution of green sulphate; it did not at all alter the colour of red cabbage juice. When a little of it was poured on the mercury, it soon lost its colour, its taste became acid, and it quickly reddened cabbage juice, even rendered green by an alkali.

To the solution remaining in the mercurial jar, a small quantity of prussiate of potash was introduced, to ascertain if any red sulphate of iron had been formed; but instead of the production of either a blue, or a white precipitate, the whole of the solution became opaque, and chocolate coloured.

Surprised at this appearance, I was at first induced to suppose, that the ammonia formed by the nitrogen of the nitrous gas and the hydrogen of the water, had been sufficient to precipitate from the sulphuric acid, the red oxide of iron produced, and that the colour of the mixture was owing to this precipitation. To dissolve any uncombined oxide that might exist in the solution, I added a very minute quantity of diluted sulphuric acid; but little alteration of colour was produced. Hence, evidently, no red oxide had been formed.

This unexpected result obliged me to theorise a second time, by supposing that nitrate of ammonia had been produced, which by combining with the white prussiate of iron, generated a new combination. But on mingling together green sulphate of iron, prussiate of potash, and nitrate of ammonia in the atmosphere, the mixture remained perfectly white.

To ascertain if any nitric acid existed, combined with any of the bases, in the impregnated solution, I introduced into it an equal bulk of diluted sulphuric acid: it became rather paler; but no green or blue tinge was produced.

That the prussic acid had not been decomposed, was evident from the bright green produced, when less than a grain of dilute nitric acid was admitted into the solution.

f. From these experiments it was evident, that no red sulphate of iron, or nitric acid, and consequently no ammonia, had been produced after the absorption of nitrous gas by green sulphate of iron. And when I compared them with the observations of Priestley, who had expelled by heat a minute quantity of nitrous gas from an impregnated solution of common sulphate of iron, and who found common air phlogisticated by standing in contact with it, I began to suspect that nitrous gas was simply dissolved in the solution, without undergoing decomposition.

g. To determine more accurately the nature of the process, I introduced into a mercurial cylinder 410 grains of solution of green sulphate of iron, occupying a space nearly equal to a cubic inch and quarter; it was saturated with nitrous gas, by absorbing 8 cubic inches. This saturated solution exhibited the same appearance as the last; and after remaining near an hour untouched, had evidently deposited no oxide of iron, nor gained any acid properties.

Into a small matrass filled with mercury, having a tight stopper with a curved tube adapted to it, the greater part of this solution was introduced; judging from the capacity of the matrass, about 50 grains of it might have been lost. To prevent common air from coming in contact with the solution, the stopper was introduced into the matrass under the mercury; the curved tube connected with a graduated cylinder filled with that substance; and the matrass brought over the side of the mercurial trough. But in spite of these precautions a large globule of common air got into the top of the matrass, from the curvature of the tube. When the heat of a spirit lamp was applied to the solution, it gave out gas with great rapidity, and gradually lost its colour. When 5 cubic inches were collected it became perfectly pale green, whilst a yellow red precipitate was deposited on the bottom of the matrass.

On pouring a little of the clear solution into prussiate of potash, it gave only white prussiate of iron.

But on introducing a particle of sulphuric acid into the solution, sufficient to dissolve some of the red precipitate, and then pouring a little of it into a solution of prussiate of potash, it gave a fine blue prussiate of iron.

Hence the red precipitate was evidently red yellow oxide of iron.

I now examined the gas, suspecting that it was nitrous oxide. On mingling a little of it with atmospheric air, it gave red vapour, and diminished. Solution of sulphate of iron introduced to the remainder, almost wholly absorbed it: the small residual globule of nitrogen could not equal one-thirtieth of a cubic inch.

Consequently it was nitrous gas, nearly pure.

Caustic potash was now introduced into the solution, till all the oxide of iron was precipitated. The solution,

when heated, gave a strong smell of ammonia, and dense white fumes when held over muriatic acid. It was kept at the heat of ebullition till the evaporation had been nearly completed. Sulphuric acid poured upon the residuum gave no yellow fumes, or nitric acid vapour in any way perceptible; even when heated and made to boil, there was no indication of the production of any vapour, except that of the sulphuric acid.

h. This experiment, compared with the others, seemed almost to prove, that nitrous gas combined with solution of pale green sulphate of iron, at the common temperature, without decomposition; and that when the impregnated solution was heated, the greater portion of gas was disengaged, whilst the remainder was decomposed by the green oxide of iron; which attracted at the same time oxygen from the water and the nitrous gas; whilst their other constituent principles, hydrogen and nitrogen entered into union as ammonia.

Whilst, however, I was reasoning upon this singular chemical change, as affording presumptive proofs in favour of the exertion of simple affinities by the constituent parts of compound substances, a doubt concerning the decomposition of the nitrous gas occurred to me. As near as I could guess at the quantity of nitrous gas contained by the impregnated solution, at least $\frac{3}{4}$ of it must have been expelled undecomposed.

More than a quarter of a cubic inch of common air had been present in the matrass; the oxygen of this common air must have combined with the nitrous gas, to form nitric acid. Might not this nitric acid have been decomposed, and furnished oxygen to the red oxide of iron, and nitrogen to the small quantity of ammonia found in the solution, as in *d*?

i. I now introduced to a solution of green sulphate

confined by mercury, nitrous gas, perfectly free from nitric acid. When the solution was saturated, a portion of it was introduced into a small matrass filled with dry mercury, in the mercurial trough. The curved tube was closed by a small cork at the top, and filled with nitrous gas; it was then adapted to the matrass, which was raised from the trough, and the solution thus effectually preserved from the contact of the atmosphere.

When the heat of a spirit lamp was applied to the matrass, it began to give out gas with great rapidity. After some time the solution lost its dark colour, and became turbid. When the production of nitrous gas had ceased, it was suffered to cool. A copious red precipitate had fallen down; which, examined by the same tests as in the last experiment, proved to be red oxide of iron.

The solution treated with lime, as before, gave ammonia; but with sulphuric acid, not the slightest indications of nitric acid.

k. Having thus procured full evidence of the decomposition of nitrous gas in the heated solution, in order to gain a more accurate acquaintance with the affinities exerted, I endeavoured to ascertain the quantity of nitrous gas decomposed by a given solution, under known circumstances.

Into a cylinder of the capacity of 20 cubic inches, inverted in mercury, 1150 grains of solution of green sulphate of iron, of specific gravity 1.4, were introduced. Nitrous gas was admitted to it, and after some time 21 cubic inches were absorbed.

The impregnated solution was thrown into a matrass, in the same manner as in the last experiment, and the same precautions taken to preserve it from the contact of atmospheric air. A quantity was lost during the

process of transferring, which, reasoning from the space occupied in the matrass by the remaining portion, as determined by experiment afterwards, must have amounted nearly to 240 grains.

The curved tube from the matrass was now made to communicate with the mercurial air-holder. By the application of heat 12·5 cubic inches of nitrous gas were collected, after the common temperature had been restored to the matrass; which was suffered to remain in communication with the conducting tube.

The solution was now pale green, that is, of its natural colour, and a considerable quantity of red oxide of iron had been deposited.

Solid caustic potash was introduced into it, till all the green oxide of iron had been precipitated, and till the solution rendered green, red cabbage juice.

A tube was now accurately connected with the matrass, bent, and introduced into a small quantity of diluted sulphuric acid. Nearly half of the fluid in it was slowly distilled into the sulphuric acid, by the heat of a spirit lamp. The impregnated acid evaporated at a heat above 212° , and gave a small quantity of crystallized salt, which barely amounted to two grains and a quarter: it had every property of sulphate of ammonia. Sulphuric acid in excess was poured on the residuum, and the whole distilled by a heat not exceeding 300° , into a small quantity of water. This water, after the process, tasted strongly of sulphuric acid; it had no peculiar odour. Tin thrown into it when heated, was not perceptibly oxidated; mingled with strontitic lime water, it gave a copious white precipitate, and after the precipitation became almost tasteless. Hence it evidently contained no nitric acid.

The 12·5 cubic inches of undecomposed gas that

came over were examined; and accounting for the small quantity of common air previously contained in the air-holder, must have been almost pure.

L Now supposing 927 grains of the impregnated solution (including the weight of the nitrous gas), to have been operated upon, this must have contained about 16·7 cubic inches of nitrous gas. But 12·5 cubic inches escaped undecomposed: hence 4·2 were decomposed; and these weigh 1·44 grains, and are composed of ·8 of oxygen, and ·64 of nitrogen.*

Consequently, the nitrous gas must have furnished ·8 of oxygen to the green oxide of iron.

But ·64 of nitrogen require ·15 of hydrogen to form ·79 of ammonia:† consequently 1 of water was decomposed, and this furnished ·85 of oxygen to the green oxide of iron.

The green oxide of iron contains $\frac{27}{100}$ oxygen; the red $\frac{48}{100}$. But the whole quantity of oxygen supplied from the water and nitrous gas is $\cdot 8 + \cdot 85 = 1\cdot65$; and calculating on the difference of the composition of the red and green oxide of iron, 5·7 grains of red oxide must have been deposited, and consequently these would saturate as much acid as ·79 grains of ammonia, or 4·1 grains of green oxide of iron.‡

And supposing the ammonia in sulphate of ammonia to be to the acid as 1 is to 3,§ 3·2 grains of sulphate of ammonia must have been formed, containing about 2·4 grains acid; and then 6·5 grains of green sulphate of iron must have been decomposed.

* Division IV. Section 5.

† Division II. Section 1.

‡ No precipitation takes place during the conversion of solution of green sulphate into red; and the acid appears saturated.

§ Division II. Section 6.

Hence we gain the following equation :—

$$\begin{array}{rcl}
 6.5 \text{ green s.} & = & 2.41 \text{ sul. acid} + 4.1 \text{ gr. ox. iron.} \\
 & & + \\
 1.44 \text{ nit. gas} & = & .64 \text{ nitrogen} + .8 \text{ oxygen.} \\
 & & + \\
 1 \text{ water} & = & .85 \text{ oxygen} + .15 \text{ hydrogen.} \\
 & & \text{equal} \\
 3.2 \text{ sul. am.} & = & 2.41 \text{ sul. acid} + .64 \text{ nit.} + .15 \text{ hyd.} \\
 & & + \\
 5.7 \text{ r. ox. iron} & = & 4.1 \text{ gr. ox. iron} + 1.6 \text{ oxygen.}
 \end{array}$$

Though the estimation of the quantities in this equation must not be considered as strictly accurate, on account of the degree of uncertainty that remains concerning the exact numerical expression of the quantities of the constituents of water, ammonia, and the other compound bodies employed; yet as founded on a simple quantity, that is, the nitrous gas decomposed, it cannot be very distant from the truth.

The sulphate of ammonia given by experiment, is considerably less than that which was really produced; much of it was probably carried off during the evaporation of the superabundant acid.

The conclusions that may be drawn from this experiment afford a striking instance of the importance of the application of the science of quantity to the chemical changes: for the data being one chemical fact, the decomposition of a given quantity of nitrous gas by known agents; the composition of nitrous gas, of water, ammonia, the oxides of iron, and sulphate of ammonia; we are able not only to determine the quantities of the simple constituents that have entered into new arrange-

ments, but likewise the composition of two compound bodies, the green and red sulphates of iron.*

m. Though from the experiments in *e* it appeared that no decomposition of nitrous gas had been produced during or even after its absorption by solution of sulphate of iron at the common temperature; yet a suspicion that it might take place slowly, and that indications of it might be given by deposition, induced me to examine minutely two impregnated solutions, one of which had been at rest, confined by mercury for 19 hours, and the other for 27. In neither of them could I discover any deposition, or alteration of colour, which might denote a change.

Two cubic inches of oxygen were admitted to half a cubic inch of one of these solutions. The oxygen was slowly absorbed, and the solution gradually lost its colour.

To ascertain if during the conversion of the nitrous gas held in solution by sulphate of iron, into nitric acid, by the oxygen of the atmosphere at the common temperature, any water was decomposed; I suffered an impregnated solution, weighing nearly two ounces, to remain in contact with the atmosphere at 57° — 62° , till it was become perfectly pale. It then had a strong acid taste, effervesced with carbonate of potash, and gave a blue precipitate with prussiate of potash. It was saturated with quick-lime, and heated: slight indications of the presence of ammonia were perceived.

As in this experiment the nitric acid had been most probably decomposed by the green oxide of iron, as in *f*, I sent oxygenated muriatic acid through an impreg-

* According to the estimation in the equation, 6.5 of dry green sulphate of iron contain 4.1 green oxide of iron, and 2.4 of Kirwan's real sulphuric acid; and 8.1 red sulphate of iron, contain 2.4 acid, and 5.7 red oxide of iron.

nated solution, till all the green oxide of iron was converted into red, and all the nitrous gas into nitric acid.

This solution saturated with potash, and heated, gave no ammoniacal smell.

From these experiments we may conclude,

1st. That solution of red sulphate of iron has little or no affinity for nitrous gas; * and that solution of common sulphate absorbs nitrous gas only in proportion as it contains green sulphate.

2ndly. That solutions of green sulphate of iron dissolve nitrous gas in quantities proportionable to their concentration, without effecting any decomposition of it at common temperatures. And the solubility of nitrous gas in solution of green sulphate, may be supposed to depend on an equilibrium of affinity, produced by the following simple attractions :

1. That of green oxide of iron for the oxygen of nitrous gas and water.

2. That of the hydrogen of the water for the nitrogen of the nitrous gas.

3. That of the principles of the sulphuric acid, for nitrogen and hydrogen.

3dly. That at high temperatures, that is, from 200° to 300°, the equilibrium of affinity producing the binary combination between nitrous gas and solution of green sulphate of iron is destroyed; the attraction of the green oxide of iron for oxygen being increased; whilst probably that of nitrogen for hydrogen is diminished.

* The muddy green colour produced in a solution of red sulphate of iron agitated in nitrous gas, depended upon impurities in the mercury. I have since found, that when the solution is completely oxygenated, the diminution is barely perceptible.

Hence the nitrous gas is either liberated,* in consequence of the affinity between oxygen and hydrogen, and oxygen and nitrogen not following the same ratio of alteration on increased temperature; or decomposed, because at a certain temperature the green oxide exerts such affinities upon water and nitrous gas, as to attract oxygen from both of them to form red oxide; whilst the still existing affinity between the hydrogen of the one, and the nitrogen of the other, disposes them to combine to form ammonia.

4thly. That the change of colour produced by introducing nitric acid to solution of common sulphate of iron, exactly analogous to that occasioned in it by impregnation with nitrous gas, is owing to the decomposition of the acid, by the combination of its oxygen with the green oxide of iron, and of its nitrous gas with the solution.

5thly. That nitrous gas in combination with solution of green sulphate of iron, is capable of exerting a strong affinity upon free or loosely combined oxygen, and of uniting with it to form nitric acid.

n. The products obtained from a solution of sulphate of iron saturated with nitrous gas, by Vauquelin and Humboldt, and their consequent mistake with regard to the nature of the process of absorption,† must have arisen from exposure of their impregnated solution to the atmosphere.

Indeed, from the acidity of it, on examination, from the small portion of ammonia, and the large quantity

* Perhaps the liberation of nitrous gas from the solution takes place at a lower temperature than its decomposition. I have always observed that the quantity of yellow precipitate is greater when the solution is rapidly made to boil. Were it possible to heat it to a certain temperature at once, probably a complete decomposition would take place.

† *Annales de Chimie*, t. lviii. p. 187.

of nitric acid obtained, it appears most probable that the whole of the nitrous gas employed was converted into nitric acid, by combining with atmospheric oxygen; for no nitric acid could have been obtained in the mode in which they operated, unless the green oxide of iron in the solution had been previously converted into red.

VIII. *On the Absorption of Nitrous Gas by Solution of green Muriate of Iron.*

a. The analogy between the affinities of the constituents of muriate and sulphate of iron, induced me to conjecture that they possessed similar powers of absorbing nitrous gas; and I soon found that this was actually the case; for on agitating half a cubic inch of solution of muriated iron, procured by dissolving iron filings in muriatic acid, in nitrous gas, the gas was absorbed with great rapidity, whilst the solution assumed a deep and bright brown tinge.

b. Proust,* who as I have before mentioned, supposes the existence of two oxides of iron only, one containing $\frac{7}{100}$ oxygen, the other $\frac{8}{100}$, has assumed, that the muriatic acid, and most other acids as well as the sulphuric, are capable of combining with these oxides, and of forming with each of them a distinct salt. He has, however, detailed no experiments on the muriates of iron.

As these salts are still more distinct from each other in their properties than the sulphates, and as these properties are connected with the phenomenon of the absorption and decomposition of nitrous gas, I shall

* Annales de Chimie, xxiii. p. 85; or Nicholson's Phil. Journal, vol. i. 4to. p. 45.

detail the observations I have been able to make upon them.

c. When iron filings have been dissolved in pure muriatic acid, and the solution preserved from the contact of air, it is of a pale green colour, and gives a white precipitate with alkaline prussiates. The alkalies throw down from it a light green oxide of iron.

When evaporated, it gives crystals almost white, which are extremely soluble in water; but insoluble in alcohol.

The solution of green muriate of iron has a great affinity for oxygen, and attracts it from the atmosphere, from nitric acid, and probably from oxygenated muriatic acid.

When red oxide of iron is dissolved in muriatic acid, or when nitric acid is decomposed by solution of green muriate of iron; the red muriate of iron is produced. The solution of this salt is of a deep brown red, its odour is peculiar, and its taste, even in a very diluted state, highly astringent. It acts upon animal and vegetable matters in a manner somewhat analogous to the oxygenated muriatic acid, rendering them yellowish white, or yellow.*

Sulphuric acid poured upon it, produces a smell resembling that of oxygenated muriatic acid. Evaporated at a low temperature, it gives an uncrystallizable dark orange-coloured salt, which is soluble in alcohol, and when decomposed by the alkalies, gives a red precipitate. With prussiate of potash it gives prussian blue.

The common muriate of iron consists of different

* Probably by giving them oxygen; whereas the green muriate and sulphate blacken animal substances; most likely by abstracting from them oxygen.

proportions of these two salts. It may be converted into red muriate by concentrated nitric acid, or into green by sulphuretted hydrogen.

d. To ascertain if solution of red muriate of iron was capable of absorbing nitrous gas, I introduced into a jar filled with mercury, a cubic inch of nitrous gas, and admitted to it nearly half a cubic inch of solution of red muriate of iron. No discoloration took place. By much agitation, however, an absorption of nearly $\cdot 2$ was produced, and the solution became of a muddy green. But this change of colour, and probably the absorption, was in consequence of oxidation of either the mercury, or some imperfect metals combined with it, by the oxygen of the red muriate. For I afterwards found, that precisely the same change of colour was produced when a solution was agitated over mercury.

e. I introduced to a cubic inch of concentrated solution of green muriate of iron, 7 cubic inches of nitrous gas, free from nitric acid; the solution instantly became coloured at the edges, and on agitation absorbed the gas with much greater rapidity than even sulphate of iron; in a minute, only a quarter of a cubic inch remained.

The solution appeared of a very dark brown, but evidently no precipitation had taken place in it, and the edges, when viewed against the light, were transparent and puce-coloured.

Five cubic inches more of nitrous gas were now dissolved in the solution. The intensity of the colour increased, and after an hour no deposition had taken place. A little of it was then examined in the atmosphere; it had a much more astringent taste than the unimpregnated solution, and effected no change in red cabbage juice. When prussiate of potash was intro-

duced into it, its colour changed to olive brown. A few drops of solution, that had accidentally fallen on the mercury, soon became colourless, and then effervesced with carbonate of potash, and tasted strongly acid.

The remainder of the impregnated solution, which must have nearly equalled .75 cubic inch, was introduced into a matrass, having a stopper and curved tube, as in the experiments on the solution of sulphate of iron; great care being taken to preserve it from the contact of air.

The matrass was heated by a spirit lamp, the curved tube being in communication with a mercurial cylinder. Near 8 cubic inches of nitrous gas were collected, when the solution became of a muddy yellow. It was suffered to cool, and examined. A small quantity of yellow precipitate covered the bottom of the matrass; the fluid was pellucid, and light green. A little of it thrown on prussiate of potash, gave a white precipitate, coloured by streaks of light blue. When the yellow precipitate was partly dissolved by sulphuric acid, a drop of the solution, mingled with prussiate of potash, gave a deep blue green.

Hence, evidently, the precipitate was red oxide of iron.

Caustic potash in excess was introduced into the remainder of the solution, and it was heated. It gave an evident smell of ammonia, and dense white fumes, when held over strong phlogisticated nitrous acid.

When half of it was evaporated, sulphuric acid in excess was poured on the remainder; muriatic acid was liberated, not perceptibly combined with any nitric acid.

f. In an experiment that I made to ascertain the quantity of nitrous gas capable of combining with solu-

tion of green muriate of iron; I found that .75 cubic inch of saturated solution absorbed about 18 of nitrous gas, which is nearly double the quantity combinable with an equal portion of the strongest solution of sulphate of iron. A part of this impregnated solution, heated slowly, gave out more gas in proportion to the quantity it contained, than the last, and consequently produced less precipitate; so that I am inclined to suppose it probable, that at a certain temperature, all the dissolved nitrous gas may be dispelled from a solution.

From these experiments we conclude,

1st. That the solution of green muriate of iron absorbs nitrous gas in consequence of nearly the same affinities as solution of green sulphate of iron; its capability of absorbing larger quantities depending most probably on its greater concentration (that is, on the greater solubility of the muriate of iron), and perhaps, in some measure, on a new combining affinity, that of muriatic acid for oxygen.

2ndly. That at certain temperatures, nitrous gas is either liberated from solution of green muriate, or decomposed, by the combination of its oxygen with green oxide of iron, and of its nitrogen with hydrogen, produced from water decomposed by the oxide at the same time.

IX. *Absorption of Nitrous Gas by Solution of Nitrate of Iron.*

a. As well as two sulphates and two muriates of iron, there exist two nitrates.* When concentrated nitric acid is made to act upon iron, nitrous gas is disengaged

* The existence of green nitrate was not suspected by Proust.

with great rapidity, and with great increase of temperature : the solution assumes a yellowish tinge, and as the process goes on, a yellow red oxide is precipitated.

Nitrate of iron made in this way, gives a bright blue, mingled with prussiate of potash ; and decomposed by the alkalies, a red precipitate. Its solution has little or no affinity for nitrous gas.

b. When very dilute nitric acid, that is, such as of specific gravity 1.16, is made to oxidate iron, without the assistance of heat, the solution gives out no gas for some time, and becomes dark olive brown : when neutralised it gives, decomposed by the alkalies, a light green precipitate ; and mingled with prussiate of potash, pale green prussiate of iron.

It owes its colour to the nitrous gas it holds in solution. By exposure to the atmosphere it becomes pale, the nitrous gas combined with it being converted into nitric acid.

It is then capable of absorbing nitrous gas, and consists of pale nitrate of iron, mingled with red nitrate.

I have not yet obtained a nitrate of iron giving only a white precipitate with prussiate of potash, that is, such as contains *only* oxide of iron at its minimum of oxidation ; for when pure green oxide of iron is dissolved by very dilute nitric acid, a small quantity of the acid is generally decomposed, which is likewise the case in the decomposition of nitre by green sulphate of iron. The solutions of nitrate of iron, however, procured in both of these modes, absorb nitrous gas with rapidity, and by sulphuretted hydrogen might probably be converted into pale nitrate.

As it is impossible to obtain concentrated solutions of pale nitrate of iron, chiefly containing green oxide, its powers of absorbing nitrous gas cannot be compared

with the muriatic and sulphuric solutions, unless they are made of nearly the same specific gravity.

Nitrous gas is disengaged by heat from the impregnated solution of nitrate of iron, at the same time that much red oxide of iron is precipitated. Whether any nitrous gas is decomposed, I have not yet ascertained; for when unimpregnated pale nitrate of iron is heated, a part of the acid, and of the water of the solution, is decomposed by the green oxide of iron;* and in consequence, ammonia and red nitrate of iron formed, whilst red oxide is precipitated.

X. *Absorption of Nitrous Gas by other Metallic Solutions.*

a. White prussiate of iron in contact with water absorbs nitrous gas to a great extent, and becomes dark chocolate.†

b. Concentrated solution of sulphate of tin, *probably* at its minimum of oxidation, absorbs one-eighth of its bulk of nitrous gas, and becomes brown, without deposition.

c. Solution of sulphate of zinc‡ absorbs about one-tenth of its volume of nitrous gas, and becomes green.

d. Solution of muriate of zinc‡ absorbs nearly the same quantity, and becomes orange brown.

e. These are all the metallic substances on which I have experimented. It is more than probable that there

* In this process nitrous oxide is sometimes given out, as will be seen hereafter.

† Hence we learn why no nitrous gas is disengaged when impregnated solution of sulphate of iron is decomposed by prussiate of potash, as in Div. IV. Sec. 7.

‡ In both of these solutions the metal is at its minimum of oxidation. The absorption of a small quantity of nitrous gas by white vitriol was observed by Priestley.

exist others possessing similar powers of absorbing nitrous gas.

Whenever the metals capable of decomposing water exist in solutions at their minimum of oxidation, the affinities exerted by them on nitrous gas and water, will be such as to produce combination. The powers of metallic solutions to combine with nitrous gas at common temperatures, as well as to decompose it at higher temperatures, will probably be in the ratio of the affinity of the metallic oxides they contain, for oxygen.

XL. The action of Sulphuretted Hydrogen on Solution of Green Sulphate of Iron, impregnated with Nitrous Gas.

a. In an experiment on the absorption of nitrous gas by solution of green sulphate of iron, I introduced an unboiled solution of common sulphate, deprived of red oxide of iron by sulphuretted hydrogen, into a jar filled with nitrous gas; the absorption took place as usual, and nearly six of gas entered into combination, the volume of the solution being unity. On applying heat to a part of this impregnated solution, the whole of the nitrous gas it contained (as nearly as I could guess), was expelled undecomposed, and no yellow precipitate produced. Prussiate of potash poured into it gave only white prussiate of iron; and when it was heated with lime, no ammoniacal smell was perceptible.

I could refer this phenomenon to no other cause than to the existence of a small quantity of sulphuretted hydrogen in the solution. That this was the real cause I found from the following experiment.

b. One part of a solution of green sulphate of iron, formed by the agitation of common sulphate of iron in

contact with sulphuretted hydrogen, was boiled for some minutes to expel the small quantity of gas retained by it undecomposed. It had then no peculiar smell, and gave a white prussiate of iron with prussiate of potash; the other part had a faint odour of sulphuretted hydrogen, and gave a dirty white precipitate with prussiate of potash. Nearly equal quantities of each were saturated with nitrous gas and heated. The unboiled impregnated solution gave out all its nitrous gas undecomposed; whilst in the boiled solution it was partly decomposed, yellow precipitate and ammonia being formed.

c. This singular phenomenon of the power of a minute quantity of sulphuretted hydrogen, in preventing the decomposition of nitrous gas and water, by green oxide of iron, will most probably take place in other impregnated solutions. It seems to depend on the strong affinity of the hydrogen of sulphuretted hydrogen for oxygen.

XII. *Additional Observations.*

a. For separating nitrous gas from gases absorbable to no great extent by water; a well boiled solution of green muriate of iron should be employed. Nitrous gas agitated in this is rapidly absorbed, and it has no affinity for, or action on, nitrogen, hydrogen, or hydrocarbonate.

b. Nitrous gas carefully obtained from mercury and nitric acid, when received under mercury, or boiled water, and absorbed by solution of green muriate, or sulphate of iron, rarely leaves a residuum of $\frac{1}{20}$ of its volume: preserved over common water, and absorbed, the remainder is generally from $\frac{1}{40}$ to $\frac{1}{90}$, from the

nitrogen disengaged by the decomposition of the common air contained in the water.

c. The nitrous gas carefully obtained from the decomposition of nitric acid of 1.26, by copper, I have hardly ever found to contain more than from $\frac{1}{30}$ to $\frac{1}{30}$ nitrogen, when received through common water: when boiled water is employed, the residuum is nearly the same as that of nitrous gas obtained from mercury.

d. Consequently the gas from those two solutions may be used in common. It is more than probable, that the small quantities of nitrogen generally mingled with nitrous gas from copper and mercury, arise either from the common air of the vessels in which it was produced, or that of the water over which it was received. There is no reason for supposing that it is generated by a complete decomposition of a portion of the acid.*

e. Whenever nitrous oxide is mingled with nitrous gas and nitrogen, it must be separated by well-boiled water; and after the corrections are made for the quantity of air disengaged from the water, the nitrous gas absorbed by the muriatic solution.

* Humboldt, who is the first philosopher that has applied the solution of sulphate of iron to ascertain the purity of nitrous gas, asserts that he uniformly found nitrous gas obtained from solution of copper in nitrous acid, to contain from six-tenths to one-tenth nitrogen.—*Annales de Chimie*, vol. xxviii. p. 147.

DIVISION V.

EXPERIMENTS AND OBSERVATIONS ON THE PRODUCTION OF
NITROUS OXIDE FROM NITROUS GAS AND NITRIC ACID,
IN DIFFERENT MODES.I. *Preliminaries.*

a. The opinions of Priestley* and Kirwan,† relating to the causes of the conversion of nitrous gas into nitrous oxide, were founded on the theory of phlogiston. The first of these philosophers obtained nitrous oxide by placing nitrous gas in contact with moistened iron filings, or the alkaline sulphures. The last by exposing it to sulphuretted hydrogen.

The Dutch chemists,‡ the latest experimentalists on nitrous oxide, have supposed that the production of this substance depends upon the simple abstraction of a portion of the oxygen of nitrous gas. They obtained nitrous oxide by exposing nitrous gas to muriate of tin, to copper in solution of ammonia, and likewise by passing it over heated sulphur.

The diminution of volume sustained by nitrous gas during its conversion into nitrous oxide, has never been accurately ascertained; it has generally been supposed to be from two-thirds to eight-tenths.

b. Nitrous gas may be converted into nitrous oxide in two modes.

First, by the simple abstraction of a portion of its oxygen, by bodies possessing a strong affinity for that

* Vol. ii. page 55.

† Phil. Trans. vol. lxxvi. page 133.

‡ Journal de Physique, tom. xliii. 323.

principle, such as alkaline sulphites, muriate of tin, and dry sulphures.

Second, by the combination of a body with a portion both of its oxygen and nitrogen, such as hydrogen, when either in a nascent form, or a peculiar state of combination.

c. Each of these modes will be distinctly treated of; and to prevent unnecessary repetitions, I shall give an account of the general manner in which the following experiments on the conversion of nitrous gas into nitrous oxide, have been conducted.

Nitrous gas, the purity of which has been accurately ascertained by solution of muriate of iron, is introduced into a graduated jar filled with dry mercury. If a fluid substance is designed for the conversion of the gas into nitrous oxide, it is heated, to expel any loosely combined air which might be liberated during the process; and then carefully introduced into the jar, by means of a small phial. After the process is finished, and the diminution accurately noted, the nitrous oxide formed is absorbed by pure water. If any nitrous gas remains, it is condensed by solution of muriate of iron; other residual gases are examined by the common tests. The quantity of nitrous oxide dissolved by the fluid is determined by a comparative experiment; and the corrections for temperature and pressure being guessed at, the conclusions drawn.

If a solid substance is used, rather more nitrous gas than that designed for the conversion, is introduced into the jar. The substance is brought in contact with the gas, by being carried under the mercury; and as a little common air generally adheres to it, a small portion of the nitrous gas is transferred into a graduated tube, after the insertion, and its purity ascertained. In

other respects the process is conducted as mentioned above.

II. *Of the Conversion of Nitrous Gas into Nitrous Oxide, by Alkaline Sulphites.*

The alkaline sulphites, particularly the sulphite of potash, convert nitrous gas into nitrous oxide, with much greater rapidity than any other bodies.

At temperature 46° , 16 cubic inches of nitrous gas were converted, in less than an hour, into 7.8 of nitrous oxide, by about 100 grains of pulverised sulphite of potash, containing its water of crystallization. No sensible increase of temperature was produced during the process, no water was decomposed, and the quantity of nitrogen remaining after the experiment, was exactly equal to that previously contained in the nitrous gas.

The nitrous oxide produced from nitrous gas by sulphite of potash, has all the properties of that generated from the decomposition of nitrate of ammonia. It gives, as will be seen hereafter, the same products by analysis. Phosphorus, the taper, sulphur, and charcoal, burn in it with vivid light. It is absorbable by water, and capable of expulsion from it unaltered, by heat.

Nitrous gas is converted into nitrous oxide by the alkaline sulphites with the same readiness, whether exposed to the light, or deprived of its influence.

The solid sulphites act upon nitrous gas much more readily than their concentrated solutions; they should, however, always be suffered to retain their water of crystallization, or otherwise they attract moisture from the gas, and render it drier, and in consequence more condensed than it would otherwise be. In case per-

fectly dry sulphites are employed, the gas should be always saturated with moisture after the experiment, by introducing into the cylinder a drop of water.

The sulphites, after exposure to nitrous gas, are either found wholly, or partially, converted into sulphates. Consequently the conversion of nitrous gas into nitrous oxide by these bodies, simply depends on the abstraction of a portion of its oxygen; the nitrogen and remaining oxygen assuming a more condensed state of existence.

If we reason from the different specific gravities of nitrous oxide and nitrous gas, as compared with the diminution of volume of nitrous gas, during its conversion into nitrous oxide, 100 parts of nitrous gas, supposing the former estimation of the composition of nitrous oxide given in Division III. accurate, would consist of 54 oxygen, and 46 nitrogen; which is not far from the true estimation. Or assuming the composition of nitrous gas, as given in Division IV., it would appear from the diminution, that 100 parts of nitrous oxide consisted of 38 oxygen, and 62 nitrogen.

III. *Conversion of Nitrous Gas into Nitrous Oxide, by Muriate of Tin, and Dry Sulphures.*

a. Nitrous gas, exposed to dry muriate of tin, is slowly converted into nitrous oxide: during this process the apparent diminution is to about one-half; but if the products are nicely examined, and the necessary corrections made, the real diminution of nitrous gas by muriate of tin, will be the same as by the sulphites; that is, 100 parts of it will be converted into 48 of nitrous oxide.

During this conversion, no water is decomposed, and

no nitrogen evolved. Solution of muriate of tin converts nitrous gas into nitrous oxide; but with much less rapidity than the solid salt.

b. Nitrous gas exposed to dry and perfectly well-made sulphures, particularly such as are produced from crystallized alum* and charcoal not sufficiently inflammable to burn in the atmosphere, is converted into nitrous oxide by the simple abstraction of a portion of its oxygen, and consequently undergoes a diminution of $\frac{5}{100}$.

It is probable, that all the bodies having strong affinity for oxygen will, at certain temperatures, convert nitrous gas into nitrous oxide. Priestley, and the Dutch chemists, effected the change by heated sulphur. Perhaps nitrous gas sent through a tube heated, but not ignited, with phosphorus, would be converted into nitrous oxide.

IV. *Decomposition of Nitrous Gas, by Sulphuretted Hydrogen.*

a. When nitrous gas and sulphuretted hydrogen are mingled together, a decomposition of them slowly takes place. The gases are diminished, sulphur deposited, nitrous oxide formed, and signs of the production of ammonia† and water perceived.

In this process no sulphuric, or sulphureous acid is produced; consequently none of the sulphur is oxidated, and of course the changes depend upon the combination of the hydrogen of the sulphuretted hydrogen, with different portions of the oxygen and nitrogen of the

* That is, alum containing sulphate of potash.

† The production of ammonia in this process was observed by Kirwan and Austin.

nitrous gas, to form water and ammonia, the remaining oxygen and nitrogen assuming the form of nitrous oxide.

This singular exertion of attractions by a simple body, appears highly improbable *à priori*, nor did I admit it, till the formation of ammonia, and the non-oxygenation of the sulphur were made evident by many experiments.

In those experiments, the diminution of the nitrous gas was not uniformly the same. It varied from $\frac{1}{10}$ to $\frac{1}{2}$. In the most accurate of them, 5 cubic inches of nitrous gas were converted into 2.2 of nitrous oxide. Consequently, the quantity of ammonia formed was .047 grains.

In experiments on the conversion of nitrous gas into nitrous oxide, by sulphuretted hydrogen, the gases should be rendered as dry as possible. The presence of water considerably retards the decomposition.

b. The sulphures* dissolved in water convert nitrous gas into nitrous oxide. This decomposition is not, however, produced by the simple abstraction of oxygen from the nitrous gas to form sulphuric acid. It depends as well on the decomposition of the sulphuretted hydrogen dissolved in the solution, or liberated from it. In this process sulphur is deposited on the surface of the fluid, sulphuric acid is formed, and the diminution,

* Solution of sulphure of strontian, or barytes, should be used. During the conversion of nitrous gas into nitrous oxide by those bodies, a thin film is deposited on the surface of the solution. This film examined, is found to consist of sulphur and sulphate. Possibly the nitrous gas is wholly decomposed by the hydrogen of the sulphuretted hydrogen in the solution, whilst the sulphate is produced from water decomposed by the sulphur to form more gas for the saturation of the hydro-sulphure.

making the necessary corrections, is nearly the same as when free sulphuretted hydrogen is employed.

It is extremely probable that sulphuretted hydrogen, in combination with the alkalies, as well as with water, is capable of being slowly decomposed by nitrous gas.

V. *Decomposition of Nitrous Gas by Nascent Hydrogen.*

a. When nitrous gas is exposed to wetted iron filings, a diminution of its volume slowly takes place; and after a certain time, it is found converted into nitrous oxide.

In this process ammonia* is formed, and the iron partially oxidated.

The water in contact with the iron is decomposed by the combination of its oxygen with that substance, and of its hydrogen with a portion of the oxygen and nitrogen of the nitrous gas, to form water and ammonia.

That the iron is not oxidated at the expense of the oxygen of the nitrous gas, appears very probable from the analogy between this process, and the mutual decomposition of nitrous gas and sulphuretted hydrogen. Besides, dry iron filings effect no change whatever in nitrous gas, at common temperatures.

I have generally found about 12 of nitrous gas converted into 5 of nitrous oxide in this process; which is not very different from the diminution by sulphuretted hydrogen. It takes places equally well in light and darkness; but more rapidly in warm weather than in cold.

* As was first observed by Priestley and Austin, and as I have proved by many experiments.

b. Nitrous gas exposed to a large surface of zinc, in contact with water, is slowly converted into nitrous oxide; at the same time that ammonia is generated, and white oxide of zinc formed. This process appears to depend, like the last, upon the decomposition of water by the affinities of part of the oxygen and nitrogen of nitrous gas, for its hydrogen, to form ammonia and water; and by that of zinc for its oxygen. Zinc placed in contact with water, and confined by mercury,* decomposes it at the common temperature. Zinc, when perfectly dry, does not in the slightest degree act upon nitrous gas.

I have not been able to determine exactly the diminution of volume of nitrous gas, during its conversion into nitrous oxide by zinc. In one experiment 20 measures of nitrous gas, containing about $\cdot 03$ nitrogen, were diminished to 9, after an exposure of eight days to wetted zinc; but from an accident, I was not able to ascertain the exact quantity of nitrous oxide formed.

c. It is probable that most of the imperfect metals will be found capable of oxidation, by the decomposition of water, when its hydrogen is attracted by the oxygen and nitrogen of nitrous gas. I have this day (April 14, 1800), examined two portions of nitrous gas, one of which had been exposed to copper filings, and the other to powder of tin, for twenty-three days.

The gas that had been exposed to copper was diminished nearly two-fifths. The taper burnt in it with an enlarged flame, blue at the edges. Hence it evidently contained nitrous oxide.

The nitrous gas in contact with tin had undergone a diminution of one-fourth only, and did not support flame.

* As I have found by experiment.

VI. *Miscellaneous Observations on the Conversion of Nitrous Gas into Nitrous Oxide.*

a. Dr. Priestley found nitrous gas exposed to a mixture of iron filings and sulphur, with water, converted after a certain time into nitrous oxide. Sulphuretted hydrogen is always produced during the combination of iron and sulphur, when they are in contact with water; and by the hydrogen of this in the nascent state, the nitrous gas is most probably decomposed.

b. Green oxide of iron moistened with water, exposed to nitrous gas, slowly gains an orange tinge, whilst the gas is diminished. Most likely it is converted into nitrous oxide; but this I have not ascertained.

c. I exposed nitrous gas to the following bodies over mercury for many days, without any diminution, or apparent change in its properties. Alcohol, saccharine matter, hydro-carbonate, sulphureous acid, and phosphorus.

d. Crystallized sulphate, and muriate of iron, absorb a small quantity of nitrous gas, and become dark-coloured on the outside; but after this absorption, (which probably depends on their water of crystallization,) has taken place, no change is effected in the gas remaining.

e. The power of iron to decompose water being much increased by increase of temperature, nitrous gas is converted into nitrous oxide much more rapidly when placed in contact with a surface of heated iron, than when exposed to it at common temperatures. During the decomposition of nitrous gas in this way, ammonia is formed.*

* As was observed by Milner. Nitrous gas passed over heated zinc, or tin, I doubt not, will be found converted into nitrous oxide.

f. The curious experiments of Rouppe,* on the absorption of gases by charcoal, compared with the phenomena noticed in this division, render it probable that hydrogen in a state of loose combination with charcoal, will be found to convert nitrous gas into nitrous oxide.

VII. *Recapitulation of Conclusions concerning the Conversion of Nitrous Gas into Nitrous Oxide.*

a. Certain bodies having a strong affinity for oxygen, as the sulphites, dry sulphures, muriate of tin, &c. convert nitrous gas into nitrous oxide, by simply attracting a portion of its oxygen; whilst the remaining oxygen enters into combination with the nitrogen, and they assume a more condensed state of existence.

b. Nitrous gas is converted into nitrous oxide by hydrogen, in a peculiar state of existence, as in sulphuretted hydrogen; and that by a series of very complex affinities. Both oxygen and nitrogen are attracted from the nitrous gas by the hydrogen, in such proportions as to form water and ammonia, whilst the remaining oxygen and nitrogen† assume the form of nitrous oxide.

c. Nitrous gas placed in contact with bodies, such as iron and zinc decomposing water, is converted into nitrous oxide, at the same time that ammonia is formed. It is difficult to ascertain the exact rationale of this process. For either the nascent hydrogen produced by the decomposition of the water by the metallic substance may combine with portions of both the oxygen and nitrogen of the nitrous gas; and thus by forming water and ammonia, convert it into nitrous oxide; or the

* *Annales de Chimie*, xxxii. p. 3.

† The decomposition and recomposition of water, in this process, are analogous to some of the phenomena observed by the ingenious Mrs. Fulhame.

metallic substance may attract at the same time oxygen from the water and nitrous gas, whilst the nascent hydrogen of the water seizes upon a portion of the nitrogen of the nitrous gas to form ammonia.

The degree of diminution, and the analogy between this process and the decomposition of nitrous gas by sulphuretted hydrogen, render the first opinion most probable.

VIII. *The Production of Nitrous Oxide during the Oxidation of Tin, Zinc, and Iron, in Nitric Acid.*

a. Dr. Priestley discovered, that during the solution of tin, zinc, and iron, in nitric acid, certain portions of nitrous oxide were produced, mingled with quantities of nitrous gas, and nitrogen, varying in proportion as the acid employed was more or less concentrated.

It has long been known that ammonia is formed during the solution of tin, zinc, and iron, in diluted nitric acid. Consequently, in these processes water is decomposed.

I had designed to investigate minutely these phenomena, so as to ascertain the quantities of water and acid decomposed, and of the new products generated; but after going through some experiments on the oxidation of tin without gaining conclusive results, the labour and sacrifice of time they demanded obliged me to desist from pursuing the subject, till I had completed more important investigations.

I shall detail the few observations which have occurred to me, relating to the production of nitrous oxide from metallic solutions.

b. When tin is dissolved in concentrated nitric acid, such as of 1·4, nitrous oxide is produced, mingled with generally more than twice its bulk of nitrous gas. In

this process but little free nitrogen is evolved, and the tin is chiefly precipitated in the form of a white powder. If the solution, after the generation of these products, is saturated with lime, and heated, the ammoniacal smell is distinct.

When nitric acid of specific gravity 1.24, is made to act upon tin; in the beginning of the process, nearly equal parts of nitrous gas and nitrous oxide are produced; as it advances, the proportion of nitrous oxide to the nitrous gas increases: the largest quantity of nitrous oxide that I have found in the gas procured from tin is $\frac{3}{4}$, the remainder being nitrous gas and nitrogen.

When tin is oxidated in an acid of less specific gravity than 1.09, the quantities of gas disengaged are very small, and consist of nitrogen, mingled with minute portions of nitrous oxide, and nitrous gas.

Whenever I have saturated solutions of tin in nitric acid of different specific gravities, with lime, and afterwards heated them, the ammoniacal smell has been uniformly perceptible, and generally most distinct when diluted acids have been employed.

c. When zinc is dissolved in nitric acid, whatever is its specific gravity, certain quantities of nitrous oxide are produced.

Nitric acids of greater specific gravity than 1.2, act upon zinc with great rapidity, and great increase of temperature. The gases disengaged from these solutions consist of nitrous gas, nitrous oxide, and nitrogen; the nitrous oxide rarely equals one-third of the whole.

When nitric acid of 1.104 is made to dissolve zinc, the gas obtained in the middle of the process consists chiefly of nitrous oxide. From such a solution I obtained gas which gave a residuum of one-sixth only

when absorbed by water. The taper burnt in it with a brilliant flame, and sulphur with a vivid rose-coloured light.

100 grains of granulated zinc, during their solution in 300 grains of nitric acid, of 1.43 diluted with 14 times its weight of water, produced 26 cubic inches of gas. Of this gas $\frac{7}{8}$ were nitrous, $\frac{1}{8}$ nitrous oxide, and the remainder nitrogen. The solution saturated with lime and heated, gave a distinct smell of ammonia.

d. During the solution of iron in concentrated nitric acid, the gas given out is chiefly nitrous; it is however generally mingled with minute quantities of nitrous oxide. When very dilute nitric acids are made to act upon iron, by the assistance of heat, nitrous oxide is produced in considerable quantities, mingled with nitrous gas and nitrogen; the proportions of which are smaller as the process advances.* The fluid remaining after the oxidation and solution of iron in nitric acid, always contains ammonia.

e. As during the solution of tin, zinc, and iron, in nitric acid, the quantity of acid is diminished in proportion as the process advances, it is reasonable to suppose that the relative quantities of the gases evolved are perpetually varying. In the beginning of a dissolution, the nitrous gas generally predominates, in the middle nitrous oxide, and at the end nitrogen.

f. During the generation of nitrous gas, nitrous oxide, and ammonia, from the decomposition of solution of nitric acid in water, by tin, zinc, and iron, very complex attractions must exist between the constituents of the substances employed. The acid and the water are

* From one of Dr. Priestley's experiments, it appears that hydrogen gas is sometimes disengaged during the solution of iron in very dilute nitric acid by heat. This phenomenon has never occurred to me.

decomposed at the same time, and in proportions different as the solution is more concentrated, by the combination of their oxygen with the metallic body.

The nitrous gas is produced by the combination of the metal with $\frac{3}{10}$ of the oxygen of the acid. The nitrous oxide is most probably generated by the decomposition of a portion of the nitrous gas disengaged, by the nascent hydrogen of the water decomposed; some of it may be possibly formed from a more complete decomposition of the acid.

The production of ammonia may arise probably from two causes; from the decomposition of the nitrous gas by the combination of the nascent hydrogen of the water with portions of its oxygen and nitrogen at the same time; and from the union of hydrogen with nascent nitrogen liberated in consequence of a complete decomposition of part of the acid.

IX. *Additional Observations on the Production of Nitrous Oxide.*

a. When nitric acid is combined with muriatic acid, or sulphuric acid,* the quantities of nitrous oxide produced from its decomposition by tin, zinc, and iron, are rather increased than diminished. The nitrous oxide obtained from these solutions is, however, never sufficiently pure for physiological experiments. It is always mingled with either nitrous gas, nitrogen or hydrogen, and sometimes with all of them.

b. From the solutions of bismuth, nickel, lead, and copper, in diluted nitric acid, I have never obtained any perceptible quantity of nitrous oxide: the gas produced is nitrous, mingled with different portions of nitrogen.

* As was discovered by Priestley, and the Dutch Chemists.

Antimony and mercury, during their solution in aqua regia, give out only nitrous gas.

Probably none of the metallic bodies, except those that decompose water at temperatures below ignition, will generate nitrous oxide from nitric acid. On cobalt and manganese I have never had an opportunity of experimenting: manganese will probably produce nitrous oxide.

c. During the solution of vegetable matters* in nitric acid, by heat, very minute portions of nitrous oxide are sometimes produced, always however mingled with large quantities of nitrous gas, and carbonic acid.

When nitric acid is decomposed by ether, fixed oils, volatile oils, or alcohol, towards the end of the process small quantities of nitrous oxide are produced, and sometimes sufficiently pure to support the flame of the taper.†

d. When green oxide of iron is dissolved in nitric acid, nitrous oxide is produced, mingled with nitrogen and nitrous gas.

e. During the conversion of green sulphate, or green muriate of iron into red, by the decomposition of dilute nitric acid, nitrous oxide is formed, mingled with different proportions of nitrous gas and nitrogen.

f. When solution of green nitrate of iron is heated, a part of the acid is decomposed, red oxide is precipitated, red nitrate formed, and impure nitrous oxide evolved.

g. When iron is introduced into a solution of nitrate of copper, the copper is precipitated in its metallic state, whilst nitrous oxide, mingled with small portions of nitrogen, is produced.‡

* Such as the leaves, bark, and wood, of trees.

† As I have observed after Priestley.

‡ As was discovered by Priestley.

Both zinc and tin precipitate copper in its metallic form from solution in the nitric acid. During these precipitations, certain quantities of nitrous oxide are generated, mingled however with larger quantities of nitrogen than that produced from decomposition by iron. In all these processes ammonia is formed, and water consequently decomposed.

The decomposition of water and nitric acid, during the precipitation of copper from solution of nitrate of copper, by tin, zinc, and iron, depends upon the strong affinity of those metals for oxygen, and their powers of combining with a larger quantity of it than copper.

X. Decomposition of Aqua Regia by Platina, and Evolution of a Gas analogous to Oxigenated Muriatic Acid, and Nitrogen.

a. De la Metherie, in his essay on different airs, has asserted that the gas produced by the solution of platina in nitro-muriatic acid, is identical with the dephlogisticated nitrous gas of Priestley. He calls it nitrous gas with excess of pure air, and affirms that it diminishes both with nitrous gas and common air.

b. I introduced into a vessel containing 30 grains of platina, 2050 grains of aqua regia, composed of equal parts, by weight, of concentrated nitric acid of 1.43, and muriatic acid of 1.16. At the common temperature, that is, 49°, no action between the acid and platina appeared to take place. On the application of the heat of a spirit lamp, the solution gradually became yellow red, and gas was given out with rapidity. Some of this gas received in a jar filled with warm water appeared of a bright yellow colour. On agitation, the greater part of it was absorbed by the water, and the remainder

extinguished flame. When it was received over mercury, it acted upon it with great rapidity, and formed on the surface a white crust.

As the process of solution advanced, the colour of the acid changed to dark red, at the same time that the production of gas was much increased; more than 40 cubic inches were soon collected in the water apparatus.

Different portions of the gas were examined; it exhibited the following properties:

1. Its colour was orange red,* and its smell exactly resembled that of oxygenated muriatic acid.

2. When agitated in boiled water, it was rapidly absorbed, leaving a residuum of rather more than one-twelfth.

3. The taper burnt in it with increased brilliancy, the flame being long, and deep red at the edges.

4. Iron introduced into it ignited, burnt with a dull red light.

5. Green vegetables exposed to it were instantly rendered white.

6. It underwent no diminution, mingled with atmospheric air.

7. When mingled with nitrous gas, it gave dense red vapour, and rapid diminution.

c. From the exhibition of these properties, it was evident that the gas produced during the solution of platina in aqua regia, chiefly consisted of oxygenated muriatic acid, or of a gas highly analogous to it. It was, however, difficult to conceive how a body, by com-

* This deep colour depended, in some measure, upon the nitro-muriatic vapor suspended in it. I have since observed that it is more intense in proportion as the heat employed for the production of the gas has been stronger. The natural colour of the peculiar gas is deep yellow.

binning with a portion of the oxygen of nitro-muriatic acid, could produce from it oxygenated muriatic acid, apparently mingled with very small portions of any other gas.

d. To ascertain whether any permanent gas was produced during the ebullition of aqua regia, of the same composition as that used for the solution of the platina; I kept a large quantity of it boiling for some time, in communication with the apparatus; the gas generated appeared to be wholly nitro-muriatic, and was absorbed as fast as produced, by the water.

e. To determine whether any nitrous oxide was mingled with the peculiar gas, as well as the nature and quantity of the unabsorbable gas, nitrous gas was gradually added to 21 cubic inches of the gas produced from a new solution, till the diminution was complete: the gas remaining equalled 2·3 cubic inches; it was unabsorbable by water, and extinguished flame.

In another experiment, when the last portions of gas from a solution were carefully received in water previously boiled, 12 cubic inches agitated in water left a residuum of 1·3; whilst the same quantity decomposed by nitrous gas, containing ·02 nitrogen, left about 1·5.

Hence it appeared that the aëriform products of the solution consisted of the peculiar gas analogous to oxygenated muriatic acid, and of a small quantity of nitrogen.

f. Consequently a portion of the nitric acid of the aqua regia had been decomposed; but if it had given oxygen both to the platina and muriatic acid, the quantity of nitrogen evolved ought to have been much more considerable.

g. To ascertain if any water had been decomposed, and the nitrogen condensed in the solution by its hydro-

gen, to form ammonia, I saturated a solution with lime, and heated it, but no ammoniacal smell was perceived.

h. To determine if any nitrogen had entered into chemical combination with muriatic acid and oxygen, so as to form an aëriform triple compound, analogous in its properties to oxygenated muriatic acid, I exposed some of the gas to mercury, expecting that this substance, by combining with its oxygen, would effect a complete decomposition; and this was actually the case: for the gas was at first rapidly diminished, and the mercury became oxidated; its volume, however, soon increased; and the residual gas appeared to be nitrous, mingled with much nitrogen. The exact proportions of each, from an accident, I could not determine.

This experiment was inconclusive, because the nitro-muriatic acid suspended in the peculiar gas, from which it can probably be never perfectly freed, acted in common with it upon the mercury, and produced nitrous gas: and this nitrous gas, at the moment of its production, formed nitrous acid by combining with the oxygen of the peculiar gas; and the nitrous acid generated* was again decomposed by the mercury; and hence nitrous gas evolved, and possibly some nitrogen.

* The decomposition of aëriform nitrous acid by mercury was first noted by Priestley, vol. iii. page 101. This decomposition I have often had occasion to observe. In reading Humboldt's paper on eudiometry, *Annales de Chimie*, xxviii. page 150, I was not a little surprised to find that he takes no notice of this fact. He seems to suppose that nitrous acid can remain aëriform, and even be condensed, in contact with mercury, without alteration. He says, "In mingling 100 parts of atmospheric air with 100 of nitrous air, the air immediately became red, but all the acid produced remained aëriform; and after eighteen hours some *drops* only of acid were formed, which *swam* upon the mercury."

i. Peculiar circumstances prevented me at this time from completely investigating the subject. It remains doubtful whether the gas consists simply of highly oxygenated muriatic acid and nitrogen,* produced by the decomposition of nitric acid from the coalescing affinities of platina and muriatic acid for oxygen; or whether it is composed of a *peculiar* gas, analogous to oxygenated muriatic acid, and nitrogen, generated from some unknown affinities.†

XI. *On the Action of the Electric Spark on a Mixture of Nitrogen and Nitrous Gas.*

Thinking it possible that nitrous gas and nitrogen might be made to combine by the action of the electric spark, so as to form nitrous oxide, I introduced 20 grain measures of each of them into a small detonating tube, graduated to grains, standing over mercury, and containing a very small quantity of cabbage juice rendered

* Lavoisier has said concerning aqua regia, "In solutions of metals in this acid, as in all other acids, the metals are first oxidated, by attracting a part of the oxygen from the compound radical. This occasions the disengagement of a particular species of gas not hitherto described, which may be called nitro-muriatic gas. It has a very disagreeable smell, and is fatal to animal life when respired; it attacks iron, and causes it to rust; it is absorbed in considerable quantities by water." *Elem. Eng.* 237.

† I have no doubt but that the gas procured from the solution of gold in aqua regia, is analogous to that produced from platina.

Some very uncommon circumstances are attendant on the solution of platina:

1st. The immense quantity of acid required for the solution of a minute quantity of platina.

2d. The great quantity of gas produced during the solution of this minute quantity.

3d. The intense red colour of the solution, and its perfectly acid properties after it ceases to act upon the metal.

green by an alkali. After electric sparks had been passed through the gases for an hour and a half, they were diminished to about 32, and the cabbage juice was slightly reddened. On introducing about 10 measures of hydrogen, and passing the electric spark through the whole, no inflammation or diminution was perceptible. Hence the condensation most probably arose wholly from the formation of nitrous acid,* by the more intimate union of the oxygen of nitrous gas with some of its nitrogen, as in the experiments of Priestley.

As the nascent nitrogen, in the decomposition of nitrate of ammonia, combines with a portion of oxygen and nitrogen, to form nitrous oxide; it is probable that nitrous oxide may be produced during the passage of nitrous gas and ammonia through a heated tube.

XII. *General Remarks.*

There are no reasons for supposing that nitrous oxide is formed in any of the processes of nature; and the nice equilibrium of affinity by which it is constituted, forbids us to hope for the power of composing it from its simple principles. We must be content to produce it, either directly or indirectly, from the decomposition of nitric acid. And as in the decomposition of nitrate of ammonia, not only all the nitrogen of the nitric acid enters into the composition of the nitrous oxide produced, but likewise that of the ammonia, this process is by far the cheapest, as well as the most expeditious. A mode of producing ammonia at little expense, has been proposed by Mr. Watt. Condensed in the sulphuric acid, it can be easily made to combine with nitric acid,

* For if nitrous oxide had been formed, it would have been decomposed by the hydrogen.

from the decomposition of nitre by double affinity. And thus, if the hopes which the experiments at the end of those researches induce us to indulge, do not prove fallacious, a substance which has been heretofore almost exclusively appropriated to the destruction of mankind, may become, in the hands of philosophy, a means of producing health and pleasurable sensation.

RESEARCH II.

INTO THE COMBINATIONS OF NITROUS OXIDE, AND ITS
DECOMPOSITION BY COMBUSTIBLE BODIES.

DIVISION I.

EXPERIMENTS AND OBSERVATIONS ON THE COMBINATIONS
OF NITROUS OXIDE.

I. Combination of Water with Nitrous Oxide.

a. THE discoverer of nitrous oxide first observed its solubility in water; and it has since been noticed by different experimentalists.

Dr. Priestley found that water dissolved about one-half of its bulk of nitrous oxide, and that at the temperature of ebullition, this substance was incapable of remaining in combination with it.*

b. I introduced to 9 cubic inches of pure water, *i. e.* water distilled under mercury, 7 cubic inches of nitrous oxide which had been obtained over mercury, from the decomposition of nitrate of ammonia, and in consequence was perfectly pure. After they had remained together for 11 hours, temperature being 46°, during which time they were frequently agitated, the gas remaining was 2·3; consequently 4·7 cubic inches had

* Experiments and Observations, vol. ii. p. 81.

been absorbed. And then, 100 cubic inches, = 25300 grains of water, will absorb 54 cubic inches, = 27 grains, of nitrous oxide.

c. The taste of water impregnated with nitrous oxide is distinctly sweetish; it is softer than common water, and, in my opinion, much more agreeable to the palate. It produces no alteration in vegetable blues, and effects no change of colour in metallic solutions.

d. Thinking that water impregnated with nitrous oxide might probably produce some effects when taken into the stomach, by giving out its gas, I drank, in June, 1799, about 3 ounces of it, but without perceiving any effects.

A few days ago, considering this quantity as inadequate, I took at two draughts nearly a pint, fully saturated; and at this time Mr. Joseph Priestley drank the same quantity.

We neither of us perceived any remarkable effects.

Since that time I have drank near three pints of it in the course of a day. In this instance it appeared to act as a diuretic, and I imagined that it expedited digestion. As a matter of taste, I should always prefer it to common water.

e. Two cubic inches of pure water, that had been made to absorb about 1.1 cubic inches of nitrous oxide; when kept for some time in ebullition, and then rapidly cooled, produced nearly 1 of gas. Sulphur burnt in this gas with a vivid rose-coloured flame.

In another experiment, in which the gas was expelled by heat from impregnated water, and absorbed again after much agitation on cooling; the residuum was hardly perceptible, and most likely depended upon some gas which had adhered to the mercury, and was liberated during the ebullition. Hence it appears that

nitrous oxide is expelled unaltered from its aqueous solution by heat.

f. I have before mentioned, Division III., that nitrous oxide, during its combination with spring water, expels the common air dissolved in it. This common air generally amounts to one-sixteenth, the volume of the water being unity. A correction on account of this circumstance must be made for the apparent deficiency of diminution, and for the common air mingled in consequence, with nitrous oxide during its absorption by common water.

g. Water impregnated with nitrous gas absorbed nitrous oxide; but the residual gas was much greater than that of common water, and gave red fumes with atmospheric air. Nitrous gas agitated for a long while over water highly impregnated with nitrous oxide, was not in the slightest degree diminished; in one experiment indeed it was rather increased; doubtless from the liberation of some nitrous oxide from the water by the agitation.

h. Nitrous oxide kept in contact with aqueous solution of sulphuretted hydrogen and often agitated, was not in the slightest degree diminished.

Sulphuretted hydrogen, introduced into a solution of nitrous oxide, was rapidly absorbed, and as the process advanced, the nitrous oxide was given out.

i. Water impregnated with carbonic acid, possessed no action upon nitrous oxide, and did not in the slightest degree absorb it. When carbonic acid was introduced to an aqueous solution of nitrous oxide, the æriform acid was absorbed, and the nitrous oxide liberated.

k. From these observations it appears that nitrous oxide has less affinity for water, than even the weaker

acids, sulphuretted hydrogen and carbonic acid; as indeed one might have conjectured *à priori* from its degree of solubility: likewise that it has a stronger attraction for water than the gases not possessed of acid or alkaline properties; it expelling from water nitrous gas, oxygen, and common air; probably hydro-carbonate, hydrogen, and nitrogen.

II. *Combinations of Nitrous Oxide with Fluid Inflammable Bodies.*

a. Vitriolic ether absorbs nitrous oxide in much larger quantities than water.

A cubic inch of ether, at temperature 52° , combined with a cubic inch and seven-tenths of nitrous oxide.

Ether thus impregnated was not at all altered in its appearance; its smell was precisely the same, but the taste appeared less pungent, and more agreeable. Nitrous oxide is liberated unaltered from ether at a very low temperature, that is, at about the boiling point of this fluid.

For expelling nitrous oxide from impregnated ether, and for ascertaining in general the quantity of gases combined with fluids, I have lately made use of a very simple method, which it may not be amiss to describe.

The impregnated fluid is introduced into a small thin tube, graduated to 0.5 cubic inches, through mercury. The quantity of fluid should never equal more than a fifth or sixth of the capacity of the tube.

The lower part of the tube is adapted to an orifice in the shelf of the mercurial apparatus, so as to make an angle of about 40° with the surface of the mercury.

The flame of a small spirit lamp is then applied to that part of the tube containing the fluid; and after

the expulsion of the gas from it, the heat is raised so as to drive out the fluid through the orifice of the tube. Thus the liberated gas is preserved in a state proper for accurate examination.

Impregnated ether, during its combination with water, gives out the greater part of its nitrous oxide. During the liberation of nitrous oxide from ether, by its combination with water, a very curious phenomenon takes place.

If the water employed is coloured, so that it may be seen in a stratum distinct from the impregnated ether, at the point of contact a number of small spherules of fluid will be perceived, apparently repulsive both to water and ether; these spherules become gradually covered with minute globules of gas, and as this gas is liberated from their surfaces, they gradually disappear.

b. Alcohol dissolves considerable quantities of nitrous oxide.

2 cubic inches of alcohol, at 52° , combined with 2.4 cubic inches of nitrous oxide. The alcohol thus impregnated had a taste rather sweeter than before, but in other physical properties was not perceptibly altered.

Nitrous oxide is incapable of remaining in combination with this fluid at the temperature of ebullition; it is liberated from it unaltered by heat.

Impregnated alcohol, during its combination with water, gives out the greater part of its combined nitrous oxide; on mingling the two fluids together, at the point of contact the alcohol becomes covered with an infinite number of small globules of gas, which continue to be generated during the whole of the combination, and in passing through the fluid renders it almost opaque.

c. The essential oils absorb nitrous oxide to a greater extent than either alcohol or ether.

·5 cubic inch of oil of carui combined with 1·2 cubic inch of nitrous oxide at 51°. The colour of the oil thus impregnated was rather paler than before.

Nitrous oxide is expelled unaltered from impregnated oil of carui, by heat.

1 of oil of turpentine absorbed nearly 2 of nitrous oxide, at 57°. Its properties were not sensibly altered from this combination, and the gas was expelled from it undecomposed, by heat.

d. As well as the essential oils, the fixed oils dissolve nitrous oxide at low temperatures, whilst at high temperatures they do not remain in combination.

1 of olive oil absorbed, at 61°, 1·2 of nitrous oxide, but without undergoing any apparent physical change.

III. *Action of Fluid Acids on Nitrous Oxide.*

a. Nitrous oxide exposed to concentrated sulphuric acid, undergoes no change, and suffers no diminution, that may not be accounted for from the abstraction of a portion of its water by the acid.

b. Nitrous oxide is scarcely at all soluble in nitrous acid, and exposed to that substance, undergoes no alteration.

c. Muriatic acid, of specific gravity 1·14 absorbs about a third of its bulk of nitrous oxide. It suffers no apparent change in its properties from being thus impregnated, and the gas is again given out from it on the application of heat.

d. Acetic acid absorbs nearly one-third of its bulk of nitrous oxide.

e. Aqua regia, that is, the nitro-muriatic acid, absorbs a very minute portion of nitrous oxide.

f. Nitrous oxide was exposed to a new compound acid, consisting of oxygenated muriatic acid, and sulphuric acid, which I discovered in July, 1799, and of which an account will be shortly published; but it was neither absorbed nor altered.

I have before mentioned that the aqueous solutions of sulphuretted hydrogen and carbonic acid, neither dissolve nor alter nitrous oxide.

IV. *Action of Saline Solutions, and other Substances, on Nitrous Oxide.*

a. Nitrous oxide exposed to concentrated solution of green sulphate of iron, at 58° , underwent no perceptible diminution; not even after it had been suffered to remain in contact with it for half an hour.

b. It underwent diminution of nearly $\cdot 2$ when agitated in contact with a solution of red sulphate of iron, the volume of the solution being unity.

c. Solution of green sulphate of iron, fully impregnated with nitrous gas, did not in the slightest degree absorb nitrous oxide, and appeared to have no action upon it.

d. Solution of green muriate of iron, whether impregnated with nitrous gas, or unimpregnated, has no affinity for, or action upon, nitrous oxide.

e. Solution of red muriate of iron in alcohol, absorbed nearly one-fifth of its bulk, of nitrous oxide.

f. Solution of prussiate of potash absorbed nearly one-third of its volume, of nitrous oxide, which was again expelled from it by heat.

g. Solution of nitrate of copper appeared to have no affinity for nitrous oxide.

h. Concentrated solution of nitrate of ammonia, at 58°, absorbed one-eighth of its bulk of nitrous oxide.

i. Solutions of alkaline sulphures absorb nitrous oxide in quantities proportionable to the water they contain; it is expelled from them unaltered by heat. None of the hydro-sulphures dissolve more than half their bulk of nitrous oxide.

k. Concentrated solutions of the sulphites possess little or no action on nitrous oxide; diluted solutions absorb it in small quantities.

l. Concentrated solution of muriate of tin absorbs about one-eighth of nitrous oxide; more dilute solutions absorb larger quantities.

From these observations we learn, that neutro-saline solutions in general, have very feeble attractions for nitrous oxide; and as solutions of green muriate, and sulphate of iron, whether free from nitrous gas, or impregnated with it, possess no action upon nitrous oxide, nitrous gas may be separated from this substance by those solutions with greater facility than nitrous oxide can be separated from nitrous gas, by water or alcohol.

Charcoal absorbs nitrous oxide as well as all other gases; and it is disengaged from it by heat.

I have as yet found no other solid body, not possessed of alkaline properties, capable of absorbing nitrous oxide in any state of existence.

The bodies possessing the strongest affinity for oxygen, the dry sulphites, muriate of tin, the common sulphures, white prussiate of potash, and green oxide of iron, do not in the slightest degree act on nitrous oxide at common temperatures.

V. Action of different Gases on Nitrous Oxide.

a. 12 measures of muriatic acid gas were mingled with 7 measures of nitrous oxide at 56° . After remaining together for a minute, they filled a space equal to $19\frac{1}{2}$ measures. When water was introduced to them, the muriatic acid was absorbed much more slowly than if it had been unmingled.

In another experiment, when the gases were saturated with water, 9 measures of each of them, when mingled and suffered to remain in contact for a quarter of an hour, filled a space nearly equal to 19; and after the muriatic acid had been absorbed by potash, the nitrous oxide remained unaltered in its properties.

From the expansion, it appears most probable that æriform muriatic acid, and nitrous oxide, have a certain affinity for each other, and that they combine when mingled together; for in the last experiment, the increase of volume cannot be accounted for by supposing that nitrous oxide undergoes less change of volume than muriatic acid, by æriform combination with water, and that the expansion depended upon the solution of some of its combined water by the muriatic acid. That muriatic acid and nitrous oxide have a slight affinity for each other, likewise appears from the absorption of nitrous oxide by aqueous solution of muriatic acid.

Thinking that nitrous oxide might attract muriatic acid from its solution in water, I exposed a minute quantity of fluid muriatic acid to nitrous oxide; but no alteration of volume took place in the gas.

b. 6 measures of nitrous oxide were mingled with 11 measures of sulphureous acid, saturated with water; after remaining at rest for six minutes, they filled a

space nearly equal to 18 measures. Exposed to water, the sulphureous acid was absorbed, but not nearly so rapidly as when in a free state. Sulphur burnt with a vivid flame in the residual nitrous oxide. 7 measures of sulphureous acid were now mingled with 8 of nitrous oxide. They filled a space nearly equal to $15\frac{3}{4}$, and no farther expansion took place afterwards.

From these experiments it appears probable that sulphureous acid, and nitrous oxide, have some affinity for each other.

c. 11 measures of carbonic acid were mingled with 8 of nitrous oxide; they filled a space nearly equal to 19 measures. On exposing the mixture to caustic potash, the carbonic acid was absorbed, and the nitrous oxide remained pure. Hence it appears that carbonic acid and nitrous oxide do not combine with each other.

d. Oxygenated muriatic acid, and nitrous oxide, were mingled in a water apparatus: there was a slight appearance of condensation; but this was most probably owing to absorption by the water; on agitation, the oxygenated muriatic acid was absorbed, and the greater part of the nitrous oxide remained unaltered.

e. Sulphuretted hydrogen and nitrous oxide, mingled together, neither expanded nor contracted; exposed to solution of potash, the acid* only was absorbed.

f. 10 measures of nitrous gas were admitted to 12 of nitrous oxide at 59° . They filled a space equal to 22, and after remaining together for an hour, had undergone no change. Solution of muriate of iron absorbed the nitrous gas without affecting the nitrous oxide.

g. Nitrous oxide was successively mingled with oxygen, atmospheric air, hydro-carbonate, phosphoretted

* The experiments of Berthollet have clearly proved the perfect acidity of this substance.

hydrogen, hydrogen, and nitrogen, at 57° ; it appeared to possess no action on any of them, and was separated by water, the gases remaining unaltered.

h. As nitrous oxide was soluble in ether, alcohol, and the other inflammable fluids, it was reasonable to suppose that its affinity for those bodies would enable them to unite with it in the aëriform state. At the suggestion of Dr. Beddoes I made the following experiment:

To 12 measures of nitrous oxide, at 54° , I introduced a single drop of ether; the gas immediately began to expand, and in four minutes filled a space equal to sixteen measures and a quarter. When an inflamed taper was plunged into the gas thus holding ether in solution, a light blue flame slowly passed through it.

A considerable diminution of temperature is most probably produced, from the great expansion of nitrous oxide during its combination with ether.

A drop of alcohol was admitted to 14 measures of nitrous oxide. In five minutes, the gas filled a space equal to fifteen and a third; but no farther diminution took place afterwards.

A minute quantity of oil of turpentine was introduced to 14 measures of nitrous oxide; it filled, in 4 minutes, a space rather less than 14; and no farther change took place afterwards. Most likely this contraction arose from the precipitation of the water dissolved in the gas by the stronger affinity of the oil for nitrous oxide. To ascertain with certainty if any oil had been dissolved by the gas, I introduced into it a small quantity of ammonia. It immediately became slightly clouded, most probably from the formation of soap, by the combination of the dissolved oil with the ammonia.

From these experiments we learn, that when nitrous

oxide is mingled with either carbonic acid, oxygen, common air, hydro-carbonate, sulphuretted hydrogen, hydrogen, or nitrogen, they may be separated from each other without making any allowance for contraction or expansion: but if a mixture of either muriatic acid, or sulphureous acid gas, with nitrous oxide, is experimented upon; in the absorption of the acid by alkalies, the apparent volume of gas condensed will be less than the real one, by a quantity equal to the sum of expansion from combination. Consequently a correction must be made on account of this circumstance.

Though alcohol, ether, essential oils, and the fluid inflammable bodies in general, dissolve nitrous oxide with much greater rapidity than water, yet as we are not perfectly acquainted with their action on unabsorbable gases, it is better to employ water for separating nitrous oxide from these substances; particularly as that fluid is more or less combined with all gases, and as we are acquainted with the extent of its action upon them.

By pursuing the subject of the solution of essential oils in gases, we may probably discover a mode of obtaining them in a state of absolute dryness. For if other gases as well as nitrous oxide, have a stronger affinity for oils than for water, water most probably will be precipitated from them during their solution of oils; and after their saturation with oil, it is likely that they are capable of being deprived of that substance by ammonia.

VI. *Action of Aëriform Nitrous Oxide on the Alkalies.*
History of the Discovery of the Combinations of Nitrous Oxide with the Alkalies.

a. When nitrous oxide in a free state is exposed to

the solid caustic alkalies and alkaline earths, at common temperatures, it is neither absorbed nor acted upon; when it is placed in contact with solutions of them in water, a small quantity is dissolved; but this combination appears to depend on the water of the solution, for the gas can be expelled unaltered, at the temperature of ebullition.

b. Caustic potash was exposed to nitrous oxide for 13 hours: the diminution was not to one-fiftieth, and this slight condensation most probably depended upon its combination with the water of the gas.

Concentrated solution of potash absorbed a fourth of its bulk of nitrous oxide. When the impregnated solution was heated, globules of gas were given out from it rapidly; but the quantity collected was too small to examine.

Soda, whether solid or in solution, exhibited exactly the same phenomena with nitrous oxide. The solution of soda absorbed near a quarter of its bulk of gas.

c. 11 measures of ammoniacal gas were mingled with 8 measures of nitrous oxide over dry mercury, both of the gases being saturated with water. No change of appearance was produced by the mixture, and they filled, after two minutes, a space equal to 19. On the introduction of a little water, the ammonia was absorbed, and the nitrous oxide remained unaltered, for it was dissolved by water as rapidly as if it had never been mingled with ammonia.*

7 measures of nitrous oxide, exposed to 6 measures of solution of ammonia in water, were in an hour dimi-

* The Dutch chemists have asserted, that mixture with ammonia prevents the absorption of nitrous oxide by water, either wholly or partially. *Journal de Physique*, t. xliii. part. ii. p. 327. It is difficult to account for their mistake.

nished to $4\frac{1}{2}$ nearly. When the solution was heated over mercury, permanent gas was produced, which was unabsorbable by a minute quantity of water, and soluble in a large quantity; consequently it was nitrous oxide.

d. Nitrous oxide was exposed to dry caustic strontian; it underwent a diminution of nearly one-fortieth, which most likely was owing to the combination of the strontian with its water.

11 measures of nitrous oxide were agitated in contact with 8 of strontian lime water: nearly 4 measures were absorbed. The impregnated solution exposed to heat, rapidly gave out its gas; 3 measures were soon collected, which, mingled with a small quantity of hydrogen, and inflamed by the taper, gave a smart detonation.

e. Nitrous oxide exposed to lime and argil, both wet and dry, was not in the slightest degree acted upon.

From these experiments it is evident that nitrous oxide in the aëriform state cannot be combined either with the alkalies, or the alkaline earths. That a combination may be effected between nitrous oxide and these substances, it must be presented to them in the *nascent state*.

The salts composed of the alkalies and nitrous oxide, are not analogous to any other compound substances, being possessed of very singular properties. Before these properties are detailed, it may not be amiss to give an account of the accidental way in which I discovered the mode of combination.

In December, 1799, designing to make a very delicate experiment, with a view to ascertain if any water was decomposed during the conversion of nitrous gas into nitrous oxide, by sulphite of potash, I exposed 200 grains of crystallized sulphite of potash, containing great superabundance of alkali, to 14 cubic inches of nitrous

gas, containing one-eighteenth nitrogen. The alkali was employed to preserve any ammonia that might be formed, in the free state, as it would otherwise combine with sulphureous acid.*

The volume of gas diminished with great rapidity; in two hours and ten minutes it was reduced to $6\frac{1}{2}$, which I considered as the limit of diminution. Accidentally, however, suffering it to remain for three hours longer, I was much surprised by finding that not quite 2 cubic inches remained, which consisted of nitrous oxide, mingled with the nitrogen that existed before the experiment.

In accounting theoretically for this phenomenon, different suppositions necessarily presented themselves.

1st, It was possible, that though sulphite of potash, and potash, separately possessed no action on free nitrous oxide, yet in combination they might exert such affinities upon it as either to absorb it, or make it enter into new combinations.

2dly. It was more probable that the caustic potash, though incapable of condensing aëriform nitrous oxide, was yet possessed of a strong affinity for it when in the *nascent state*, and that the nitrous oxide condensed in the experiment had been combined in this state with the free alkali.

To ascertain if the compound of potash and sulphite of potash with sulphate, was capable of acting upon nitrous oxide, I suffered a quantity of this substance to remain in contact with the gas for near a day: no change whatever took place.

* Sulphureous acid saturates more potash than sulphuric acid, so that most probably during the conversion of sulphite of potash into sulphate, portions of sulphureous acid are disengaged.

To determine whether the diminution of nitrous oxide depended upon its absorption in the nascent state, by the peculiar compound of potash and sulphite of potash, or if it was simply owing to the alkali, I mingled a solution of sulphite of potash with caustic soda: the salt, after being evaporated at a low temperature, was exposed to nitrous gas. The nitrous oxide formed was absorbed, but in rather less quantities than when alkaline sulphite of potash was employed.

Hence it was evident that the alkali was the agent that had condensed the nitrous oxide in those experiments, for soda is incapable of combining either with sulphate, or sulphite of potash.

To ascertain whether any change in the constitution of the nitrous oxide had been produced by the condensation, I introduced a small quantity of sulphite of potash, with excess of alkali, that had absorbed nitrous oxide, into a long and thin cylindrical tube filled with mercury; and inclining it at an angle of 35° with the plane of the mercury, applied the heat of a spirit lamp to that part of the tube containing the salt; when the glass became very hot, gas was given out with rapidity; in less than a minute the tube was full. This gas was transferred into another tube, and examined; it proved to be nitrous oxide in its highest state of purity;* for a portion of it absorbed by common water, left no more than a residuum of $\frac{1}{15}$, and sulphur burnt in it with a vivid rose-coloured flame.

Being now satisfied that the alkalies were capable of combining with nitrous oxide; to investigate with pre-

* Hence we learn that sulphite of potash, when strongly heated, does not decompose nitrous oxide, even in the *nascent state*.

cision the nature of these new compounds, I proceeded in the following manner.

VII. *Combination of Nitrous Oxide with Potash.*

a. Into a solution of sulphite of potash, which had been made by passing sulphureous acid gas from a mercurial air-holder into caustic potash dissolved in water, I introduced 17 grains of dry potash. The whole, evaporated at a low temperature, gave 143 grains of salt. This salt was not *wholly* composed of sulphite of potash and potash; it contained as well, a minute quantity of carbonate, and sulphate of potash, formed during the evaporation.*

120 grains of it finely pulverised, and retaining the water of crystallization, were exposed to 15 cubic inches of nitrous gas, over mercury. The nitrous gas diminished with great rapidity, and in three hours a cubic inch and nine-tenths only remained, which consisted of nearly one-third nitrous oxide, and two-thirds nitrogen that had pre-existed in the nitrous gas. The increase of weight of the salt could not be determined, as some of it was lost by adhering to the vessel in which the combination was effected, and to the mercury. It presented no distinct series of crystallizations, even when examined by the magnifier; rendered green vegetables blues, and its taste was very different from that of the remaining quantity of salt that had been exposed to the atmosphere. A portion of it strongly heated over mercury, gave out gas with great rapidity,

* See the excellent memoir of Fourcroy and Vauquelin on the sulphureous acid, and its combinations. *Annals de Chimie*, ii. 54. Or Nicholson's *Phil. Journal*, vol. i. p. 313.

which had all the properties of the purest nitrous oxide.

When water was poured upon some of it, no gas was given out, and the whole was equably and gradually dissolved. Alcohol, as well as ether, appeared incapable of dissolving any part of it.

When muriatic acid was introduced into it, confined by mercury, a rapid effervescence took place. Part of the gas disengaged was sulphureous acid, and carbonic acid; the remainder was nitrous oxide.

b. I made a number of experiments upon salts procured in the manner I have just described, with a view to obtain the compound of nitrous oxide and potash, free from admixture of other salts.

When the mixed salt was boiled in alcohol or ether, no part of it appeared to be dissolved. Finding that little or no gas was given out during the ebullition of concentrated solutions of the mixed salts, I attempted to separate the sulphate, sulphite, and carbonate of potash, from the combination of nitrous oxide and potash, by successive evaporations and crystallizations. But though in this way it was nearly freed from sulphate of potash, yet the extreme and nearly equal solubility of the other salts, prevented me from completely separating them from each other.

By exposing, however, very finely pulverized sulphite of potash, mingled with alkali, for a great length of time to nitrous gas, it was almost wholly converted into sulphate; and after the separation of this by solution, evaporation, and crystallization, at a low temperature, I obtained the new combination, mingled with very little carbonate of potash, and still less of sulphite.

The minute quantity of sulphite chiefly appeared in very small crystals; distinct from the mass of salt,

which possessed no regular crystallization, and was almost wholly composed of the new compound, intimately mingled with a little carbonate. The new compound, as nearly as I could estimate from the quantity of nitrous oxide absorbed, consisted of about 3 alkali, to 1 of nitrous oxide, by weight.

It exhibited the following properties:—

1. Its taste was caustic, and possessed of a pungency different from either potash or carbonate of potash.

2. It rendered vegetable blues green, which might possibly depend upon the carbonate of potash mixed with it.

3. Pulverised charcoal mingled with a few grains of it, and inflamed, burnt with slight scintillations. Projected into zinc in a state of fusion, a slight inflammation was produced.

4. When either sulphuric, muriatic, or nitric acid was introduced to it under mercury, it gave out nitrous oxide, mingled with a little carbonic acid.

5. Thrown into a solution of sulphuretted hydrogen, gas was disengaged from it, but in quantities too minute to be examined.

6. When carbonic acid was thrown into a solution of it in water, gas was disengaged; on examination it proved to be nitrous oxide.

7. A concentrated solution of it kept in ebullition in a cylinder, confined by mercury, gave out a few globules of gas, which were too minute to be examined, and probably consisted of common air previously contained in the water.

c. In the experiments made to ascertain these properties all the salt was expended, otherwise I should have endeavoured to ascertain what quantity of gas would have been liberated by heat from a given weight; and

likewise what would have been the effects of admixture of it with oil. When some of the mixed salt was mingled with oil of turpentine, part of it was dissolved, and the fluid became white; but no gas was given out. On this coarse experiment, however, I cannot place much dependence. If the combination of nitrous oxide and potash is capable of combining with oil without decomposition, barytes and strontian* will probably separate the oil from it, and thus it may possibly be obtained in a state of purity.

In a rough experiment made on the conversion of nitrous gas into nitrous oxide, by concentrated solution of sulphite of potash with excess of alkali, very little of the nitrous oxide was absorbed. Hence it is probable that water lessens the affinity of potash for nascent nitrous oxide.

VIII. *Combination of Nitrous Oxide with Soda.*

The union of nitrous oxide with soda is effected in the same manner as with potash. The alkali, mingled by solution and evaporation, with either sulphite of soda, or of potash, is exposed to nitrous gas; the nitrous oxide is condensed by it at the moment of generation, and the combination effected.

As far as I have been able to observe, nitrous oxide is not absorbed to so great an extent by soda, as potash.

I have not yet been able to obtain the combination of nitrous oxide with soda in its pure state. To the attainment of this end, difficulties identical with those

* Unless the sum of affinity of the potash, oil, nitrous oxide, and earths, should be such as to enable the nitrous oxide to combine with the earth, whilst the oil and alkali remained in combination, &c.

noticed in the last section present themselves. It is extremely difficult to procure the soda perfectly free from carbonic acid, and though by using sulphite of potash the sulphate formed is easily separated, yet still evaporation and crystallization will not disengage the sulphite and carbonate from the new compound.

The compound of soda and nitrous oxide, mingled with a little sulphite and carbonate of soda, was rapidly soluble, both in warm and cold water, without effervescence. Its solution, heated to ebullition, gave out no gas. The taste of the solid salt was caustic, and more acrid than that of the mixture of carbonate and sulphite of soda. When cast upon zinc in fusion, it burnt with a white flame. When heated to 400° or 500°, it gave out nitrous oxide with rapidity. Nitrous oxide was expelled from it by the sulphuric, muriatic, and carbonic acids; *I believe*, by sulphuretted hydrogen.*

IX. *Combination of Nitrous Oxide with Ammonia.*

I attempted to effect this combination by converting nitrous gas into nitrous oxide, by sulphite of ammonia, wetted with strong solution of caustic ammonia, but without success; for the whole of the nitrous oxide produced remained in a free state.

When I exposed sulphite of potash, mingled by solution and evaporation with highly alkaline carbonate of ammonia,† to nitrous gas, the diminution was nearly

* For when a little of the mixed salt was introduced into a solution of sulphuretted hydrogen, globules of gas were given out during the solution.

† Carbonate of ammonia formed at a high temperature, containing near 60 per cent. alkali, and capable of combining with small quantities of acids without giving out its carbonic acid. Of this salt a particular account will be given in the experiments on the ammoniacal salts, which I have often mentioned in the course of this work.

one-fourth more than if pure sulphite of potash had been employed. Hence it appears most likely that ammonia is capable of combination with nitrous oxide in the nascent state.

In the experiments on the conversion of nitrous gas into nitrous oxide, by nascent hydrogen, and by sulphuretted hydrogen, Research I., Division V., probably the water formed at the same time with the ammonia and nitrous oxide, prevented them from entering into combination; *possibly* the peculiar compound was formed, but in quantities so minute as not to be distinguished from simple ammonia;* for even the existence of ammonia in these processes, is but barely perceptible.

If it should be proved by future experiments, that in the decomposition of nitrous gas by nascent hydrogen, a peculiar compound of nitrous oxide, water and ammonia, is formed, it will afford proofs in favour of the doctrine of predisposing affinity; † for then this decomposition might be supposed to depend upon the disposition of oxygen, hydrogen, and nitrogen, to assume the states of combination in which they might form a triple compound, of water, nitrous oxide, and ammonia.

Nitrous oxide might probably be made to combine

* It may not be amiss to mention some appearances taking place in the decomposition of nitrous gas by sulphuretted hydrogen, though it is useless to theorise concerning them. The sulphur deposited is at first yellow; as the process proceeds, it becomes white, and in some instances I have suspected a diminution of it.

† Predisposing affinity, the existence of which at first consideration it is difficult to admit, may be easily accounted for by *supposing* the attractions of the simple principles of compound substances. And this doctrine will apply in all instances where the constitution of bodies is known. Predisposing affinity ought not to be considered as the affinity of *non-existing* bodies for each other; but as the mutual affinity of their simple principles, disposing them to assume new arrangements.

with ammonia, by exposing a mixture of nitrous gas and æriform ammonia, to the sulphites.

It is probable that nitrous oxide may be combined with ammonia, by means of double affinity. Perhaps sulphate of ammonia and the combination of potash with nitrous oxide mingled together in solution, would be converted into sulphate of potash and the compound of nitrous oxide, and ammonia.

X. Probability of forming Compounds of Nitrous Oxide and the Alkaline Earths.

I attempted to combine nitrous oxide with lime and strontian, by exposing sulphites of lime and strontian with excess of earth, to nitrous gas; but this process did not succeed: the diminution took place so slowly as to destroy all hopes of gaining any results in a definite time. Sulphite of potash is decomposable by barytes, strontian, and lime;* consequently it was impossible to employ this substance to effect the combination.

As the dry sulphures, when well made, convert nitrous gas into nitrous oxide, it is probable that the union of the earths with nascent nitrous oxide may be effected by exposing nitrous gas to their sulphures, containing an excess of earth.

Perhaps the combination of nitrous oxide with strontian may be effected by introducing the combination of potash and nitrous oxide into strontian lime water.

It is probable that nitrous oxide may be combined with clay and magnesia, by exposing these bodies, mingled with sulphite of potash or soda, to nitrous gas.

* See the above-mentioned elaborate memoir of Fourcroy and Vauquelin.

XI. *Additional Observations on the Combinations of Nitrous Oxide with the Alkalies.*

A desire to complete physiological investigations relating to nitrous oxide, has hitherto prevented me from pursuing, to a greater extent, the experiments on the combination of this substance with the alkalies, &c. As soon as an opportunity occurs, I purpose to resume the subject.

The observations detailed in the foregoing sections are sufficient to show that nitrous oxide is capable of entering into intimate union with the fixed alkalies: and as the compounds formed by this union are insoluble in alcohol, decomposable by the acids, and heat, and possessed of peculiar properties, they ought to be considered as a new class of saline substances.

If it is thought proper, on a farther investigation of their properties, to signify them by specific names, they may, according to the usually adopted fashion of nomenclature, be called *nitroxis*: thus the *nitroxi of potash* would signify the salt formed by the combination of nitrous oxide with potash.

Future experiments must determine the different affinities of nitrous oxide for the alkalies, and alkaline earths.

With regard to the uses of these new compounds it is difficult to form a guess. When they are obtained pure, and fully saturated with nitrous oxide, on account of the low temperature at which their gas is liberated, they will probably constitute detonating compounds. From their facility of decomposition by the weaker acids, they may possibly be used medicinally, if ever the evolution of nitrous oxide in the stomach should be found beneficial in diseases.

XII. *The properties of Nitrous Oxide resemble those of Acids.*

If we were inclined to generalise, and to place nitrous oxide among a known class of bodies, its properties would certainly induce us to consider it as more analogous to the acids than to any other substances; for it is capable of uniting with water and the alkalies, and is insoluble in most of the acids. It differs, however, from the stronger acids, in not possessing the sour taste,* and the power of reddening vegetable blues: and from both the stronger and weaker acids, in not being combinable when in a perfectly free state, at common temperatures, with the alkalies. If it should be proved by future experiments, that condensation by cold gave it the capability of immediately forming neutro-saline compounds with the alkalies; it ought to be considered as the weakest of the acids. Till those experiments are made, its extraordinary chemical and physiological properties are sufficient to induce us to consider it as a body *sui generis*.

It is a singular fact that nitrous gas, which contains in its composition a quantity of oxygen so much greater than nitrous oxide, should nevertheless possess no acid properties. It is uncombinable with alkalies, very little soluble in water, and absorbable by the acids.

* The different persons who have respired nitrous oxide have, as will be seen hereafter, given different accounts of the taste; the greater number have called it sweet, some metallic. One of my friends, in a letter to me dated Nov. 13, 1799, containing a detail of some experiments made on the respiration of nitrous oxide, at Birmingham, denotes the taste of it by the term "sweetish faintly acidulous." To me the taste both of the gas and of its solution in water, has always appeared faintly sweetish.

DIVISION II.

ON THE DECOMPOSITION OF NITROUS OXIDE BY COMBUSTIBLE BODIES. ITS ANALYSIS. OBSERVATIONS ON THE DIFFERENT COMBINATIONS OF OXYGEN AND NITROGEN.

I. *Preliminaries.*

FROM the phenomena mentioned in Res. I. Div. III.* it appears that the combustible bodies burn in nitrous oxide at certain temperatures. The experiments in this Division were instituted for the purpose of investigating the precise nature of these combustions, with a view of ascertaining exactly the composition of nitrous oxide.

It will be seen hereafter that very high temperatures are required for the decomposition of nitrous oxide, by most of the combustible bodies, and that in this process heat and light are produced to a very great extent. These agents alone are possessed of a considerable power of action on nitrous oxide ; of which it is necessary to give an account, that we may be able to understand the phenomena in the following sections.

II. *Conversion of Nitrous Oxide into Nitrous Acid, and a Gas analogous to Atmospheric Air, by Ignition.*

a. Dr. Priestley asserts, that nitrous oxide exposed for a certain time to the action of the electric spark, is rendered immiscible with water, and capable of diminution with nitrous gas, without suffering any alteration of

* Section 2.

volume; and likewise that the same changes are effected in it by exposure to ignited incombustible bodies.*

The Dutch chemists state, that the electric spark passed through nitrous oxide, occasions a small diminution of its volume, and that the gas remaining is analogous to common air.† They conclude that this change depends on the separation of its constituent parts, oxygen and nitrogen, from each other.

None of these chemists have suspected the production of nitrous acid in this process.

b. Nitrous oxide undergoes no change whatever from the simple action of light. I exposed some of it, confined by mercury, for many days to this agent, often passing through it concentrated rays by means of a small lens. When examined it appeared, as well as I could estimate, of the same degree of purity as at the beginning of the experiment.

c. A temperature below that of ignition effects no alteration in the constitution of nitrous oxide. I passed nitrous oxide from a retort containing decomposing nitrate of ammonia, through a green glass tube, strongly heated in an air-furnace, but not suffered to undergo ignition. The gas, received in a water apparatus, exhibited the same properties as the purest nitrous oxide; some of it absorbed by water, left a residuum of not quite one-thirteenth.

d. The action of the electric spark for a long while continued, converts nitrous oxide into a gas analogous to atmospheric air, and nitrous acid.

* Vol. ii. page 91.

† Journal de Physique, tom. xliii. part ii. page 330. They effected the same change by passing it through a heated tube. Dr. Priestley had published an account of similar experiments more than two years before.

I passed about 150 strong shocks from a small Leyden phial, through 7 ten-grain measures of pure nitrous oxide. After this it filled a space rather less than six measures: the mercury was rendered white on the top, as if it had been acted on by nitric acid. Six measures of nitrous gas mingled with the residual gas of the experiment, over mercury covered by a little water, gave red fumes, and rapid diminution. In five minutes the volume of the gases nearly equalled ten. Thermometer in this experiment was 58° .

Electric sparks were passed for an hour and half through 7 ten-grain measures of nitrous oxide over mercury covered with a little red cabbage juice, previously saturated with nitrous oxide, and rendered green by an alkali. After the process the gas filled a space equal to rather more than six measures and half, and the juice was become of a pale red. The gas was introduced into a small tube filled with pure water, and agitated; no absorption was perceptible: 7 measures of nitrous gas added to it gave red fumes, and after six minutes a diminution to $9\frac{1}{4}$ nearly. $6\frac{1}{2}$ measures of common air from the garden, with 7 of nitrous gas, gave exactly 9.

In this experiment it was evident that nitrous oxide was converted into a gas analogous to atmospheric air, at the same time that an acid was formed. There could be little doubt but that this was the nitrous acid. To ascertain it, however, with greater certainty, the electric spark was passed through 6 measures of nitrous oxide, over a little solution of green sulphate of iron, confined by mercury. As the process went on, the colour of the solution became rather darker. When the diminution was complete, a little prussiate of potash was added to the solution. A precipitate of pale blue prussiate of iron was produced.

c. Nitrous oxide was passed from decomposing nitrate of ammonia, through a porcelain tube well glazed inside and outside, strongly ignited in an air-furnace, and communicating with the water apparatus. The gas collected was rendered opaque by dense red vapour. It appeared wholly unabsorbable by water. After the precipitation of its vapour, a candle burnt in it with nearly the same brilliancy as in atmospheric air. 20 measures of it that had been agitated in water immediately after its production, mingled with 40 measures of nitrous gas, diminished to about 47.5; whereas 20 measures that had remained unagitated for some time after their generation, introduced to the same quantity of nitrous gas, gave nearly 49. 20 measures of atmospheric air, with 40 of the same nitrous gas, were condensed to 46.

The water with which the gas had been in contact, was strongly acid. A little of it poured into a solution of green sulphate of iron, and then mingled with prussian alkali, produced a green precipitate. Hence the acid it contained was evidently nitrous.

That no source of error could have existed in this experiment from fissure in the tube, I proved, by sending water through it whilst ignited, after the process, from the same retort in which the nitrate of ammonia had been decomposed; a few globules of air only were produced, not equal to one-tenth of the volume of the water boiled, and which were doubtless previously contained in it.

I have repeated this experiment two or three times, with similar results; whenever the air was agitated in water immediately after its production, it gave *almost* the same diminution with nitrous gas as common air; when, on the contrary, it has been suffered to remain

for some time in contact with the phlogisticated nitrous acid suspended in it, the condensation has been less with nitrous gas by five or six hundred parts. Hence I am inclined to believe, that if it were possible to condense all the nitrous acid formed, immediately after its generation, so as to prevent it from absorbing oxygen from the permanent gas, this gas would be found identical with the air of the atmosphere.

The changes effected by fire on nitrous oxide are not analogous to those produced by it in other bodies; for the power of this agent seems generally *uniform*, either in wholly separating the constituent principles of bodies from each other, or in making them enter into more intimate union.*

It is a singular phenomenon, that whilst it condenses one part of the oxygen and hydrogen of nitrous oxide, in the form of nitrous acid, it should cause the remainder to expand, in the state of atmospheric air. Does not this fact afford an inference in favour of the *chemical* composition of atmospheric air?

III. *Decomposition of Nitrous Oxide by Hydrogen, at the Temperature of Ignition.*

In the following experiments on the decomposition of nitrous oxide by hydrogen, the gases were carefully generated in the mercurial apparatus, and their purity ascertained by the tests mentioned in Research I. They were measured in small tubes graduated to grains, and

* On the one hand, it decomposes ammonia into hydrogen and nitrogen, whilst on the other, it converts free oxygen and nitrogen into nitrous acid. It likewise converts nitrous gas into nitrous acid and nitrogen. Till we are more accurately acquainted with the nature of heat, light, and electricity, we shall probably be unable to explain these phenomena.

then transferred into the detonating tube, which was eight-tenths of an inch in diameter, and graduated to ten grain measures.

The space occupied by the gases being noted after the inflammation by the electric shock, green muriate of iron, and prussiate of potash, were successively introduced, to ascertain if any nitrous acid had been formed. The absorption, if any took place, was marked, and the gases transferred into a narrow grain-measure tube, and their bulk and composition accurately ascertained.

b. The hydrogen employed was procured from water by means of zinc and sulphuric acid. 50 grain-measures of it fired by the electric spark, with 30 grain-measures of oxygen containing one-eleventh nitrogen, gave a residuum of about 4. Nitrous gas mingled with those 4, indicated the presence of rather less than 1 of unconsumed oxygen. In another experiment 23 of it, with 20 of the same oxygen left rather more than 6 residuum.

The nitrous oxide was apparently pure, for it left a remainder of about .05 only, when absorbed by common water.

c. 50 of hydrogen were fired with 40 of nitrous oxide; the concussion was very great, and the light given out bright red; no perceptible quantity of nitrous acid was formed; the residual gas filled a space equal to 52. No part of it was absorbable by water; it gave no diminution with nitrous gas; when it was mingled with a little oxygen, and again acted on by the electric spark, an inflammation and slight diminution was produced.

d. 33 of hydrogen were fired with 35 of nitrous oxide: nitrous acid was produced in very minute quantity; the gas that remained was not absorbable by

water, and filled a space equal to 37 grains. Nitrous gas mingled with these, underwent a very slight diminution.

e. 46 hydrogen were fired with 46 nitrous oxide. The quantity of nitrous acid formed was just sufficient to tinge the white prussiate of potash. The gases filled a space equal to 49, gave no perceptible diminution with nitrous gas, and did not inflame with oxygen.

f. 40 hydrogen were fired with 39 nitrous oxide; no perceptible quantity of nitrous acid was formed. The residual gas filled a space equal to 41; was unabsorbable by water, underwent no diminution when mingled with nitrous gas, or when acted on by the electric spark in contact with oxygen.

g. 20 hydrogen were fired with 64 nitrous oxide; after detonation the expansion of the gases was greater in this experiment than any of the preceding ones; dense white fumes were observed in the cylinder, and a slow contraction of volume took place. After a little green muriate of iron had been admitted, the gases filled a space equal to 73: prussiate of potash mingled with the muriate, gave a deeper blue than in any of the preceding experiments. The residual gas was unabsorbable by water: 65 of it, mingled with 65 of nitrous gas, diminished to 93; whilst 65 of common air, with 65 of nitrous gas, gave 84.

h. 8 of hydrogen were fired with 54 of nitrous oxide; the same phenomena as were observed in the last experiment took place; nitrous acid was formed; after the absorption of which the residual gas filled a space equal to 55. 50 of this, with an equal quantity of nitrous gas, diminished to 76. In these processes the temperatures were from 56° to 61° .

These experiments are selected as the most accurate

of nearly fifty, made on the inflammation of different quantities of nitrous oxide and hydrogen.

As Mr. Keir found muriatic acid in the fluid, produced by the inflammation of oxygen and hydrogen in closed vessels, in Dr. Priestley's experiments, I preserved the residual gas of about 3 cubic inches of nitrous oxide, that had been detonated at different times with less than a cubic inch and half of hydrogen; but solution of nitrate of silver was not clouded when agitated in this gas, nor when introduced into the detonating tube in which the inflammation had been made.

From these experiments we learn that nitrous oxide is decomposable at the heat of ignition, by hydrogen, in a variety of proportions.

When the quantity of hydrogen very little exceeds that of the nitrous oxide, both of the gases disappear, water is produced, no nitrous acid is formed, and the volume of nitrogen evolved is rather greater than that of the nitrous oxide decomposed.

When the quantity of hydrogen is less than that of the nitrous oxide, water, nitrous acid, oxygen and nitrogen are generated in different proportions; one part of the nitrous oxide is most probably wholly decomposed by the hydrogen, and the other part converted into nitrous acid and atmospheric air, in consequence of the ignition.

From experiments *c*, *d*, and *e*, the composition of nitrous oxide may be deduced. In experiment *d*, 39 of nitrous oxide were decomposed by 40 of hydrogen, and converted into 41 of nitrogen.

Now from *b* it appears that 40 of hydrogen require for their condensation about 20.8 of oxygen in volume; so that founding the estimation upon the quantity of hydrogen consumed, 100 parts of nitrous oxide would

consist nearly of 63·1 of nitrogen, and 36·9 of oxygen. But 41 of nitrogen weigh 12·4, Res. I. Div. I. Consequently, deducing the composition of nitrous oxide from the quantity of nitrogen evolved, 100 parts of it would consist of 63·5 nitrogen, and 36·5 oxygen.

These estimations are very little different from those which may be deduced from the other experiments, and the coincidence is in favour of their accuracy.

From the following experiment it appears that the temperature required for the decomposition of nitrous oxide by hydrogen must be higher than that which is necessary to produce the inflammation of hydrogen with oxygen. I introduced into small tubes filled with equal parts of nitrous oxide and hydrogen, standing on a surface of mercury, iron wires ignited to different degrees, from the dull red to the vivid white heat. The gases were always inflamed by the white and vivid red heats; but never by the dull red heat, though the last uniformly inflamed mixtures of oxygen and hydrogen, and atmospheric air and hydrogen.

Dr. Priestley* first detonated together nitrous oxide and hydrogen; his experiment was repeated by the Dutch chemists, who found that when a small quantity of hydrogen was employed, the nitrous oxide was partially converted into a gas analogous to common air. Their estimation of its composition, which is not far removed from the truth, was founded on this phenomenon.†

* Vol. ii. p. 83.

† Journal de Physique, tom. xliii. part 2. p. 331. They supposed it to consist of about 37·5 oxygen, and 62·5 nitrogen. The nearness of this account to the truth is singular, when we consider that they were neither acquainted with the specific gravity of nitrous oxide, nor with the production of nitrous acid in this experiment.

IV. *Decomposition of Nitrous Oxide by Phosphorus.*

a. Phosphorus introduced into pure nitrous oxide at common temperatures, is not at all luminous. It is capable of being fused, and even sublimed in it, without undergoing acidification, and without effecting any alteration in its composition.

About 2 grains of phosphorus were fused, and gradually sublimed, in 2 cubic inches of pure nitrous oxide, over mercury, by the heat of a burning lens. No alteration was produced in the volume of gas; and a portion of it absorbed by water, left a residuum of one-twelfth only.

Phosphorus was sublimed in pure nitrous oxide over mercury, in a dark room, by an iron heated *nearly* to ignition; but no luminous appearance was perceptible, nor was any gas decomposed.

b. Phosphorus decomposes nitrous oxide at the temperature of ignition, with greater or less rapidity, according to the degree of heat. We have already seen, that when phosphorus in active inflammation is introduced into nitrous oxide, it burns with intensely vivid light.

Phosphorus was sublimed by a heated wire in a jar filled with nitrous oxide, standing over warm mercury. In this state of sublimation an iron heated dull red was introduced to it by being rapidly passed through the mercury; a light blue flame surrounded the wire, and disappeared as soon as it ceased to be red.

To phosphorus sublimed as before, in nitrous oxide, over warm mercury, a thick wire ignited to whiteness was introduced; a terrible detonation took place, and the jar was shattered in pieces.

By employing thick conical jars,* containing only a small quantity of nitrous oxide, I effected the detonation several times with safety; but on account of the great expansion of the elastic products, the jar was generally either raised from the mercury, or portions of gas were thrown out of it. Hence I was unable to ascertain the exact changes produced by this mode of decomposition.

c. As my first attempts to ascertain the constitution of nitrous oxide were made on its decomposition by phosphorus, I employed many different modes of partially igniting this substance in it over mercury, so as to produce a combustion without explosion.

The first method adopted was inflammation by means of oxygenated muriate of potash. A small particle of oxygenated muriate of potash was inserted into the phosphorus to be burnt. On the application of a wire, moderately hot, to the point of insertion, the salt was decomposed by the phosphorus, and sufficient fire generated and partially applied by the slight explosion, to produce the combustion of the phosphorus, without the previous sublimation of any part of it.

The second way employed was the ignition of a part of the phosphorus, by means of the combustion of a small portion of tinder of cotton,† or paper, in contact with it, by the burning glass.

* Experiments on the detonation of nitrous oxide with phosphorus in this way require great attention. The detonating jar should be very conical; the nitrous oxide employed should never equal more than one-eighth of the capacity of the jar. The wire for the inflammation must be very thick, and curved so as to be easily introduced into the jar. When ignited, it must be instantaneously passed through the heated mercury into the jar.

Perhaps the electric spark might be advantageously applied for detonating phosphoric vapour with nitrous oxide.

† It will be seen hereafter that these bodies are easily inflamed in nitrous oxide.

The third, and most successful mode, was by introducing into the graduated jar containing the nitrous oxide, the phosphorus in a small tube containing oxygen, so balanced as to swim on the surface of the mercury, without communicating with the nitrous oxide. The phosphorus was fired in the oxygen with an ignited iron wire, by which at the moment of combustion, the tube containing it was raised into the nitrous oxide, and thus the inflammation continued.

d. In different experiments, made with accuracy, I found that the whole of a quantity of nitrous oxide was never decomposable by ignited phosphorus; the combustion always stopped when the nitrous oxide remaining was to the nitrogen evolved as about 1 to 5; likewise that the volume of nitrogen produced was rather less than that of the nitrous oxide decomposed, and that this deficiency arose from the formation of nitrous acid by the intense ignition produced during the process.

Of one experiment I shall give a detail.

Temperature being 48° , two cubic inches of pure nitrous oxide, which had been generated over mercury, were introduced into a jar of the capacity of 9 cubic inches, graduated to $\cdot 1$ cubic inch, and much enlarged at the base. A grain of phosphorus was inserted into a small vessel about one-third of an inch long, and half an inch in diameter, containing about 15 grain measures of very pure oxygen; this vessel, which swam on the surface of the mercury, was carefully introduced into the jar containing the nitrous oxide. The phosphorus was fired by means of a heated wire, and before the oxygen was wholly consumed, the vessel containing it elevated into the nitrous oxide. The combustion was extremely vivid and rapid.

After the atmospheric temperature was restored, the gas was rendered opaque by dense white vapour. When this had been precipitated, and the small vessel removed from the jar, the gas filled a space nearly equal to 1·9 cubic inch. On introducing to it a little solution of green muriate of iron, and prussiate of potash, green prussiate of iron was produced: hence, evidently nitrous acid had been formed.

On the admission of pure water, an absorption of rather more than ·3 took place.

The 16 measures remaining underwent no perceptible diminution with nitrous gas; the taper plunged into them was instantly extinguished.

To ascertain if the phosphoric acid produced in the experiments made under mercury did not in some measure prevent the decomposition of the whole of the nitrous oxide by the phosphorus, I introduced into a mixture of 5 nitrogen and 1 nitrous oxide, ignited phosphorus; but it was immediately extinguished.*

The Dutch chemists found that phosphorus might be fused in nitrous oxide without being luminous. They assert that phosphorus in a state of inflammation, introduced into this gas, was immediately extinguished; though when taken out into the atmosphere, it again burnt of its own accord.† It is difficult to account for their mistake.

V. *Decomposition of Nitrous Oxide by Phosphoretted Hydrogen.*

a. It has been mentioned in Research II. Division I.

* Phosphorus burnt feebly and with a white flame in a mixture of 4 nitrogen and 1 nitrous oxide.

† Journal de Physique, xliii. 328.

that phosphoretted hydrogen and nitrous oxide possess no action on each other, at atmospheric temperatures.

Phosphoretted hydrogen mingled with nitrous oxide, is capable of being inflamed by the electric spark, or by ignition.

b. E. 1. 10 grain measures of phosphoretted hydrogen, carefully produced by means of phosphorus and solution of caustic alkali, were mingled with 52 measures of nitrous oxide. The electric spark passed through them, produced a vivid inflammation. The elastic products were clouded with dense white vapour, and after some minutes filled a space nearly equal to 60. On the introduction of water, no absorption took place. When 43 of nitrous gas were admitted, the whole diminished to 70.

E. 2. 25 of nitrous oxide were fired with 10 of phosphoretted hydrogen, by the electric spark. After detonation* they filled a space exactly equal to 25. On the admission of solution of green sulphate of iron, and prussiate of potash, no blue or green precipitate was produced. On the introduction of water, no diminution was perceived. 25 of nitrous gas mingled with them, gave exactly 50.

E. 3. 10 of nitrous oxide, mingled with 20 of phosphoretted hydrogen, could not be inflamed.

25 of nitrous oxide, with 20 phosphoretted hydrogen, inflamed. The gas, after detonation, was rendered opaque by dense white vapour, and filled a space nearly equal to 45. No absorption took place when water was introduced. On admitting a little oxygen, no white fumes, or diminution, was perceived. The electric

* In this experiment, as in the last, dense white vapour was produced.

spark passed through the mixture produced an explosion, with great diminution.

c. From *E. 1*, it appears, that when a small quantity of phosphoretted hydrogen is inflamed with nitrous oxide, both the phosphorus and hydrogen are consumed; whilst the superabundant nitrous oxide, is converted into nitrous acid and atmospheric air, by the ignition; or a certain quantity is partially decomposed into atmospheric air by the combination of a portion of its oxygen with the combustible gas.

From *E. 2*, we learn, that when the phosphoretted hydrogen and nitrous oxide are to each other as 25 to 10 nearly, they both disappear, whilst nitrogen is evolved, and water and phosphoric acid is produced. Reasoning concerning the composition of nitrous oxide from this experiment, we should conclude that it was composed of about 38 oxygen, and 62 nitrogen.

The result of *E. 3*, is interesting; we are taught from it that the affinity of phosphorus for the oxygen of nitrous oxide is stronger than that of hydrogen, at the temperature of ignition; so that when phosphoretted hydrogen is mingled with a quantity of nitrous oxide, not containing sufficient oxygen to burn both its constituent parts, the phosphorus only is consumed, whilst the hydrogen is liberated.

In repeating the experiments with phosphoretted hydrogen that had remained for some hours in the mercurial apparatus, I did not gain exactly the same results; for a larger quantity of it was required to decompose the nitrous oxide, than in the former experiments; doubtless from its having deposited a portion of its phosphorus. They confirm, however, the above mentioned conclusions.

In the course of experimenting, I passed the electric

spark, for a quarter of an hour, through about 60 measures of phosphoretted hydrogen. It underwent no alteration of volume. Phosphorus was apparently precipitated from it, and it had wholly lost its power of inflaming, in contact with common air.

VI. *Decomposition of Nitrous Oxide by Sulphur.*

From the phenomenon before mentioned,* relating to the combustion of sulphur in nitrous oxide, it was evident that this gas was only decomposable by it, at a much higher temperature than common air.

I introduced into sulphur in contact with nitrous oxide, over mercury heated to 112° — 114° , a wire intensely heated. It lost much of its heat in passing through the mercury, but still appeared red in the vessel. The sulphur rapidly fused, and sublimed without being at all luminous. This experiment was repeated five or six times, but in no instance could the combustion of sulphur, by means of the ignited wire, be effected.

I inflamed sulphur in nitrous oxide in the same manner as phosphorus; namely, by introducing it into the small vessel filled with oxygen, and igniting it by means of the heated wire. In these experiments the sulphur burnt with a vivid rose-coloured light, and much sulphuric, with a little sulphureous acid, was formed.

Experimenting in this way, I was never, however, able to decompose more than one-third of the quantity of nitrous oxide employed; not only the nitrogen evolved, but likewise the sulphuric and sulphureous acids produced, stopping the combustion.

* Res. I. Div. III. s. 2.

I found that sulphur in a state of vivid inflammation, when introduced into a mixture of one-fourth nitrogen, and three-fourths nitrous oxide, burnt with a flame very much enlarged, and of a vivid rose colour. In one-third nitrogen, and two-thirds nitrous oxide, it burnt feebly with a yellow flame. In equal parts of nitrous oxide and nitrogen, it was instantly extinguished.

Sulphur burnt feebly, with a light yellow flame, when introduced ignited into a mixture of 5 nitrous gas, and 6 nitrous oxide. In one-third nitrous oxide, and two-thirds nitrous gas, it was instantly extinguished. From many circumstances, I am inclined to believe that sulphur is incapable, at any temperature, of slowly decomposing nitrous oxide, so as to burn in it with a blue flame, forming sulphureous acid alone. It appears to attract oxygen from it only when intensely ignited, so as to form chiefly sulphuric acid, and that with great rapidity, and vivid inflammation.

VII. *Decomposition of Nitrous Oxide by Sulphuretted Hydrogen.*

a. Though nitrous oxide and sulphuretted hydrogen do not act upon each other at common temperatures, yet they undergo a mutual decomposition when mingled together in certain proportions, and ignited by the electric spark.

From more than twenty experiments made on the inflammation of sulphuretted hydrogen in nitrous oxide, I select the following as the most conclusive and accurate. The temperature at which they were made was from 41° to 49° .

b. E. 1. About 35 measures of nitrous oxide were

fired with 10 of sulphuretted hydrogen ; the expansion during inflammation was very great, and the flame sky-blue. Immediately after, the gases filled a space equal to 48 nearly. White fumes were then formed, and they gradually contracted to 40. On the admission of a little strontian lime-water, a slight absorption took place, with white precipitation ; and the volume occupied by the residual gas nearly equalled 37. On admitting nitrous gas to these, no perceptible diminution took place.

E. 2. 20 sulphuretted hydrogen, with 25 nitrous oxide could not be inflamed.

30 nitrous oxide, with 22 sulphuretted hydrogen, could not be inflamed.

35 nitrous oxide, with 20 sulphuretted hydrogen, inflamed with vivid blue light and great expansion. After the explosion, the gases filled exactly the same space as before the experiment ; no white fumes were perceived, and no farther contraction occurred. On the addition of strontian lime water, a copious precipitation, with diminution, took place ; and the residual gas filled a space nearly equal to $35\frac{1}{2}$.

E. 3. 47 nitrous oxide, and 14 sulphuretted hydrogen, inflamed. After the explosion, the gases filled a space nearly equal to 65 ; then white fumes formed, and they gradually diminished to 52. On the introduction of muriate of strontian, a copious white precipitate was produced ; and on the addition of water, no further absorption took place. To the residual 52, about 20 of nitrous gas were added ; they filled together a space equal to about 67.

c. In none of the experiments made on the inflammation of sulphuretted hydrogen and nitrous oxide, could I ascertain with certainty the precipitation of

sulphur. In one or two processes the detonating tube was rendered a little white at the points of contact with the mercury; but this was most probably owing to the oxidation of the mercury, either by the heated sulphuric acid formed, or from nitrous acid produced by the ignition. The presence of nitrous acid I could not ascertain in these processes by my usual tests, because the combustion of sulphur over white prussiate of iron, converts it into light green.

When I introduced an inflamed taper into about 3 parts of sulphuretted hydrogen, and 2 parts of nitrous oxide, in which proportions they could not have been fired by the electric spark, a blue flame passed through them, and much sulphur was deposited on the sides of the vessel. But this sulphur most probably owed its formation to the decomposition of a portion of sulphuretted hydrogen not burnt, by the sulphureous acid formed from the combustion of the other portion.

We may then conclude with probability, that sulphuretted hydrogen and nitrous oxide will not decompose each other, when acted on by the electric spark, unless their proportions are such as to enable the whole of the sulphuretted hydrogen to be decomposed, so that both of its constituents may become oxygenated, by attracting oxygen from the nitrous oxide: likewise, that when the sulphuretted hydrogen is at its *maximum* of inflammation, the hydrogen and sulphur form with the whole of the oxygen of nitrous oxide, water and sulphureous acid; *E. 2*: whereas at its *minimum* they produce water, and chiefly, *perhaps* wholly, sulphuric acid; at the same time that the nitrous oxide partially decomposed, is converted into nitrogen, and a gas analogous to atmospheric air, or into nitrogen, nitrous acid, and atmospheric air. *E. 1. E. 3.*

By pursuing those experiments, and using larger quantities of gas, we may probably be able to ascertain from them with accuracy, the composition of sulphuric and sulphureous acids.

I own I was disappointed in the results, for I expected to have been able to ascertain from them, the relative affinities of sulphur, and hydrogen for the oxygen of nitrous oxide, at the temperature of ignition. I conjectured that nitrous oxide, mingled with excess of sulphuretted hydrogen, would have been decomposed, and one of the principles of it evolved unaltered, as was the case with phosphoretted hydrogen.

If we estimate the composition of nitrous oxide from the quantity of nitrogen produced in *E. 2.* it is composed of about 61 nitrogen, and 39 oxygen.

VIII. *Decomposition of Nitrous Oxide by Charcoal.*

An account of the analysis of nitrous oxide by charcoal is given in Res. I. Div. III. I have lately made two experiments on the combustion of charcoal in nitrous oxide, in which every precaution was taken to prevent the existence of sources of error. Of one of these I shall give a detail.

Ex. Temperature being 51° , about a grain of charcoal, which had been exposed for some hours to a red heat, was introduced whilst ignited, under mercury, and transferred into a graduated jar, containing 3 cubic inches of pure nitrous oxide, standing over dry mercury.

The focus of a burning lens was thrown on the charcoal; it instantly inflamed, and burnt with great vividness for near a minute, the gas being much expanded. The focus was continually applied to it for ten minutes, when the process appeared at an end. The gases, when

the common temperature and pressure were restored, filled a space equal to 4.2 cubic inches.

On introducing into them a few grain-measures of solution of green muriate of iron, for the double purpose of saturating them with moisture, and ascertaining if any nitrous acid had been formed, no change of volume took place; and prussiate of potash gave with the muriate a white precipitate only.

On the admission of a small quantity of concentrated solution of caustic potash, a diminution of the gas slowly took place; when it was complete the volume equalled about 3.05 cubic inches. By agitation in well boiled water, about .9 of these were absorbed; the remainder appeared to be pure nitrogen.

The difference between the estimation founded upon the nitrogen evolved, and that deduced from the carbonic acid generated in this experiment, is not nearly so great as in that of Res. I. Div. III. Taking about the mean proportions, we should conclude that nitrous oxide was composed of about 38 oxygen, and 62 nitrogen.

Charcoal burnt with greater vividness than in common air, in a mixture of one-third nitrogen and two-thirds nitrous oxide. In equal parts of nitrous oxide and nitrogen, its light was barely perceptible. In one-third nitrous oxide, and two-thirds nitrogen, it was almost immediately extinguished.

As charcoal burns vividly in nitrous gas, when it has been previously ignited to whiteness, I introduced it into a mixture of equal parts of nitrous oxide and nitrous gas; it burnt with a deep and bright red.

IX. Decomposition of Nitrous Oxide by Hydro-Carbonate.

Nitrous oxide, and hydro-carbonate, possess no action on each other, except at high temperatures. When mingled in certain proportions, and exposed to the electric shock, a new arrangement of their principles takes place.

E. 1. Temperature being 53°, 35 of nitrous oxide, mingled with 15 of hydro-carbonate, were fired by the electric spark; the inflammation was very vivid, and the light produced, bright red. After the explosion, the space occupied by the gases equalled about 60. On the admission of solution of strontian, a copious white precipitate was produced, and the gas diminished by agitation, to rather more than 35. When 36 of nitrous gas were added to these, white fumes appeared and the whole diminished to 62. When a little muriatic acid was poured on the white precipitate from the solution of strontian, gas was evolved from it, and it was gradually dissolved.

E. 2. 22 nitrous oxide were inflamed with 20 hydro-carbonate; after the explosion, they filled a space equal to 45; when strontian lime water was introduced, white precipitation took place, and the diminution was to 31.

To these 31, 14 of nitrous oxide were admitted, and the electric spark passed through them; an inflammation took place: carbonic acid was formed, after the absorption of which, the gas remaining filled a space equal to 43, and did not diminish with nitrous gas.

The hydro-carbonate employed in these experiments was procured from alcohol by means of sulphuric acid. In another set of experiments made with less accuracy, the same general results were obtained. Whenever

hydro-carbonate inflamed with nitrous oxide, both its constituents were oxygenated; in all cases carbonic acid was formed, and in no instance free hydrogen evolved, or charcoal precipitated.

In the decomposition of nitrous oxide by hydro-carbonate, the residual nitrogen is less than in other combustions. This circumstance I am unable to explain.

Reasoning from analogy, there can be little doubt, but that when hydro-carbonate is inflamed with excess of nitrous oxide, it will be only partially decomposed, or converted into nitrogen, nitrous acid, and atmospheric air.

The Dutch Chemists have asserted, that charcoal does not burn in nitrous oxide, except in consequence of the previous decomposition of the gas by the hydrogen always contained in this substance; and likewise, that when hydro-carbonate and nitrous oxide were mingled together, and fired by the electric spark, the hydrogen only was burnt, whilst the charcoal was precipitated.

It is difficult to account for these numerous mistakes. Their theory of the *non-respirability* of nitrous oxide was founded upon them. They supposed that the chief use of respiration was to deprive the blood of its superabundant carbon, by the combination of atmospheric oxygen with that principle; and that nitrous oxide was highly fatal to life, because it was incapable of de-carbonating the blood!!*

X. Combustion of Iron in Nitrous Oxide.

I introduced into a jar of the capacity of 20 cubic inches, containing 11 cubic inches of nitrous oxide, over

* Journal de Physique, xliii. 334.

mercury, a small quantity of fine iron wire twisted together, and having affixed to it a particle of cork. On throwing the focus of a burning glass on the cork, it instantly inflamed, and the fire was communicated to the wire, which burnt with great vividness for some moments, projecting brilliant white sparks. After it had ceased to burn, the gas was increased in volume rather more than three-tenths of an inch. The nitrous acid tests were introduced, but no acid appeared to have been formed. On exposing the gas to water, near 4.2 cubic inches were absorbed: the 7.1 remaining appeared to be pure nitrogen.

From this experiment it is evident that iron at the temperature of ignition, is capable of decomposing nitrous oxide; likewise that it is incapable of burning in it when it contains more than three-fifths nitrogen.

I attempted to inflame zinc in nitrous oxide, in the same way as iron; but without success. By keeping the focus of a burning glass upon some zinc filings, in a small quantity of nitrous oxide, I converted a little of the zinc into white oxide, and consequently decomposed a portion of the gas.

XI. *Combustion of Pyrophorus in Nitrous Oxide.*

Pyrophorus, which inflames in nitrous gas, and atmospheric air, at or even below 40°, requires for its combustion in nitrous oxide a much higher temperature. It will not burn in it, or alter it, even at 212°.

I have often inflamed pyrophorus in nitrous oxide over mercury, by means of a wire strongly heated, but not ignited. The light produced by the ignition of pyrophorus in nitrous oxide is white, like that produced by it in oxygen: in nitrous gas it is red.

When pyrophorus burns out in nitrous oxide, a little increase of the volume of gas is produced. Strontian lime water agitated in this gas becomes clouded ; but the quantity of carbonic acid formed is extremely minute. I have never made any delicate experiments on the combustion of pyrophorus in nitrous oxide.

XII. *Combustion of the Taper in Nitrous Oxide.*

It has been noticed by different experimentalists, that the taper burns with a flame considerably enlarged in nitrous oxide : sometimes with a vivid light and crackling noise, as in oxygen ; at other times with a white central flame, surrounded by a feeble blue one.

My experiments on the combustion of the taper in nitrous oxide, were chiefly made with a view to ascertain the cause of the double flame.

When the inflamed taper is introduced into pure nitrous oxide, it burns at first with a brilliant white light, and sparkles as in oxygen. As the combustion goes on, the brilliancy of the flame diminishes ; it gradually lengthens, and becomes surrounded with a pale blue cone of light, from the apex of which much unburnt charcoal is thrown off, in the form of smoke. The flame continues double to the end of the process.

When the residual gases are examined after combustion, much nitrous acid is found suspended in them ; and they are composed of carbonic acid, nitrogen, and about one-fourth of undecomposed nitrous oxide.

The double flame depends upon the nitrous acid formed by the ignition ; for it can be produced by plunging the taper into common air containing nitrous acid vapour, or into a mixture of nitrous oxide and nitrogen, through which nitrous acid has been diffused. It

is never perceived in the combustion of the taper, till much nitrous acid is formed.

In attempting to respire some residual gas of nitrous oxide, in which a taper had burnt out, I found it so highly impregnated with nitrous acid, as to disable me from even taking it into my mouth.

The taper burns in a mixture of equal parts nitrous oxide and nitrogen, at first with a flame nearly the same as that of a candle in common air; white. Before its extinction the interior white flame, and exterior blue flame, are perceived.

The taper is instantly extinguished in a mixture of one-fourth nitrous oxide, and three-fourths nitrogen.

In a mixture of equal parts nitrous oxide and nitrous gas, the taper burns at first with nearly as much brilliancy as in pure nitrous oxide; gradually the double and feeble flame is produced.

XIII. *On the Combustion of different Compound Bodies in Nitrous Oxide.*

All the solid and fluid compound inflammable bodies on which I have experimented, burn in nitrous oxide, at high temperatures. Wood, cotton, and paper, are easily inflamed in it by the burning glass. During their combustion, nitrous acid is always formed, carbonic acid, and water produced, and nitrogen evolved, rather less in bulk than the nitrous oxide decomposed.

I have already mentioned that alcohol and ether are soluble in nitrous oxide. When an ignited body is introduced into the solution of alcohol, or ether in nitrous oxide, a slight explosion takes place.

XIV. *General Conclusions relating to the Decomposition of Nitrous Oxide, and to its Analysis.*

From what has been said in the preceding sections, it appears that the inflammable bodies, in general, require for their combustion in nitrous oxide, much higher temperatures than those at which they burn in atmospheric air, or oxygen.

When intensely heated they decompose it, with the production of much heat and light, and become oxygenated.

During the combustion of solid or fluid bodies, producing flame, in nitrous oxide, nitrous acid is generated, most probably from a new arrangement of principles, analogous to those observed in sect. 2, by the ignition of that part of the gas not in contact with the burning substance. Likewise when nitrous oxide in excess is decomposed by inflammable gases, nitrous acid, and sometimes a gas analogous to common air, is produced, doubtless from the same cause.

Pyrophorus is the only body that inflames in nitrous oxide, below the temperature of ignition.

Phosphorus burns in it with the blue flame, probably forming with its oxygen only phosphoreous acid at the dull red heat, and with the intensely vivid flame, producing phosphoric acid at the white heat.

Hydrogen, charcoal, sulphur, iron, and the compound inflammable bodies, decompose it only at heats equal to, or above that of ignition: *probably* each a different temperature.

From the phenomena in section 5, it appears, that at the temperature of intense ignition, phosphorus has a stronger affinity for the oxygen of nitrous oxide than

hydrogen; and reasoning from the different degrees of combustibility of the inflammable bodies, in mixtures of nitrous oxide and nitrogen, and from other phenomena, we may conclude with probability, that at about the white heat, the affinity of the combustible bodies for oxygen takes place in the following order: phosphorus, hydrogen, charcoal,* iron, sulphur, &c.

This order of attraction is very different from that obtaining at the red heat; in which temperature charcoal and iron have a much stronger affinity for oxygen than either phosphorus or hydrogen.†

The smallest quantity of oxygen given in the different analyses of nitrous oxide just detailed, is thirty-five hundred parts; the greatest proportion is thirty-nine.

Taking the mean estimations from the most accurate experiments, we may conclude that 100 grains of the known ponderable matter of nitrous oxide, consist of about 36.7 oxygen, and 63.3 nitrogen; or taking away decimals, of 37 oxygen to 63 nitrogen; which is identical with the estimation given in Research I.

XV. *Observations on the Combinations of Oxygen and Nitrogen.*

During the decompositions of the combinations of oxygen and nitrogen by combustible bodies, a considerable momentary expansion of the acting substances, and the bodies in contact with them, is generally produced, connected with increased temperature; whilst light is often generated to a great extent.

* As is proved by the decomposition of oxide of iron and sulphuric acid by charcoal, at that temperature.

† Hydrogen at or about the red heat, appears to attract oxygen stronger than phosphorus. See Dr. Priestley's Experiments, vol. i. page 262.

Of the causes of these phenomena we are at present ignorant. Our knowledge of them must depend upon the discovery of the precise nature of heat and light, and of the laws by which they are governed. The application of general hypotheses to isolated facts can be of little utility; for this reason I shall at present forbear to enter into any discussions concerning those agents, which are imperceptible to the senses, and known only by solitary effects.

Analysis and synthesis clearly prove that oxygen and nitrogen constitute the known ponderable matter of atmospheric air, nitrous oxide, nitrous gas, and nitric acid.

That the oxygen and nitrogen of atmospheric air exist in chemical union, appears almost demonstrable from the following evidences.

1st. The equable diffusion of oxygen and nitrogen through every part of the atmosphere, which can hardly be supposed to depend on any other cause than an affinity between these principles.*

2dly. The difference between the specific gravity of atmospheric air, and a mixture of 27 parts oxygen and 73 nitrogen, as found by calculation; a difference ap-

* That attraction must be called chemical, which enables bodies of different specific gravities to unite in such a manner as to produce a compound, in every part of which the constituents are found in the same proportions to each other. Atmospheric air, examined after having been at perfect rest in closed vessels, for a great length of time, contains in every part the same proportions of oxygen and nitrogen; whereas, if no affinity existed between these principles, following the laws of specific gravity, they ought to separate; the oxygen forming the inferior, the nitrogen the superior stratum.

The supposition of the *chemical* composition of atmospheric air, has been advanced by many philosophers. The two first evidences have been often noticed.

parently owing to expansion in consequence of combination.

3dly. The conversion of nitrous oxide into nitrous acid, and a gas analogous to common air, by ignition.

4thly. The solubility of atmospheric air undecomposed in water.

ATMOSPHERIC AIR, then, may be considered as the least intimate of the combinations of nitrogen and oxygen.*

It is an elastic fluid, permanent at all known temperatures, consisting of $\cdot 73$ nitrogen and $\cdot 27$ oxygen. It is decomposable at certain temperatures, by most of the bodies possessing affinity for oxygen. It is soluble in about thirty times its bulk of water, and as far as we are acquainted with its affinities, incapable of combining with most of the simple and compound substances. 100 cubic inches of it weigh about 31 grains at 55° temperature, and 30 atmospheric pressure.

NITROUS OXIDE is a gas unalterable in its constitution, at temperatures below ignition. It is composed of oxygen and nitrogen, existing, *perhaps*, in the most intimate union which those substances are capable of assuming.† Its properties approach to those of acids. It is decomposable by the combustible bodies at very high temperatures, is soluble in double its volume of water, and in half its bulk of most of the inflammable fluids. It is combinable with the alkalies, and capable of forming with them peculiar salts. 100 grains of it are composed of about 63 nitrogen and 37 oxygen. 100

* [This view he afterwards relinquished, and considered atmospheric air merely a mixture of oxygen and azote. Vide his Elements of Chemical Philosophy—article, Oxygen.]

† For it is unalterable by those bodies which are capable of attracting oxygen from nitrous gas and nitrous acid, at common temperatures.

cubic inches of it weigh 50 grains, at 55° temperature, and 30 atmospheric pressure.

NITROUS GAS is composed about .56 oxygen, and .44 nitrogen, in intimate union. It is soluble in twelve times its bulk of water, and is combinable with the acids, and certain metallic solutions; it is possessed of no acid properties, and is decomposable by most of the bodies that attract oxygen strongly, at high temperatures. 100 cubic inches of it weigh about 34 grains, at the mean temperature and pressure.

NITRIC ACID is a substance permanently aëriform at common temperatures, composed of about 1 nitrogen to 2.3 oxygen. It is soluble to a great extent in water, and combinable with the alkalies, and nitrous gas. It is decomposable by most of the combustible bodies, at certain temperatures. 100 cubic inches of it weigh, at the mean temperature and pressure, nearly 76 grains.

RESEARCH III.

DIVISION I.

EXPERIMENTS AND OBSERVATIONS ON THE EFFECTS PRODUCED UPON ANIMALS BY THE RESPIRATION OF NITROUS OXIDE.

I. *Preliminaries.*

THE term *respirable*, in its physiological application, has been differently employed. Sometimes by the respirability of a gas has been meant, its power of supporting life for a great length of time, when repeatedly applied to the blood in the lungs. At other times all gases have been considered as respirable, which were capable of introduction into the lungs by voluntary efforts, without any relation to their vitality.

In the last sense the word respirable is most properly employed. In this sense it is used in the following sections.

Non-respirable gases are those, which when applied to the external organs of respiration, stimulate the muscles of the epiglottis in such a way as to keep it perfectly close on the glottis; thus preventing the smallest particle of gas from entering into the bronchia, in spite of voluntary exertions; such are carbonic acid, and acid gases in general.*

* See the curious experiments of Rosier, *Journal de Physique*, 1786, vol. i. p. 419.

Of respirable gases, or those which are capable of being taken into the lungs by voluntary efforts,

One only has the power of uniformly supporting life ; —atmospheric air. Other gases, when respired, sooner or later produce death ; but in different modes.

Some, as nitrogen and hydrogen, effect no positive change in the venous blood. Animals immersed in these gases die of a disease produced by privation of atmospheric air, analogous to that occasioned by their submersion in water, or non-respirable gases.

Others, as the different varieties of hydro-carbonate, destroy life by producing some positive change* in the blood, which probably immediately renders it incapable of supplying the nervous and muscular fibres with principles essential to sensibility and irritability.

Oxygen, which is capable of being respired for a much greater length of time than any other gas, except common air, finally destroys life ; first producing changes in the blood, connected with new living action.†

After experiments, to be detailed hereafter, made upon myself and others, had proved that nitrous oxide was respirable, and capable of supporting life for a longer time than any of the gases, except atmospheric air and oxygen, I was anxious to ascertain the effects of it upon animals, in cases where its action could be carried to a full extent ; and to compare the changes occasioned by it in their organs, with those produced by other powers.

* As appears from the experiments of Dr. Beddoes ; likewise those of Mr. Watt.

† As appears from the experiments of Lavoisier and Dr. Beddoes ; and as will be seen hereafter.

II. *On the Respiration of Nitrous Oxide by warm-blooded Animals.*

The nitrous oxide employed in the following experiments was procured from nitrate of ammonia, and received in large jars, filled with water previously saturated with the gas. The animal was introduced into the jar, by being carried under the water; after its introduction, the jar was made to rest on a shelf, about half an inch below the surface of the water; and the animal carefully supported, so as to prevent his mouth from resting in the water.

This mode of experimenting, either under water or mercury, is absolutely necessary, to ascertain with accuracy the effects of pure gases on living beings. In some experiments that I made on the respiration of nitrous oxide, by animals that were plunged into jars of it opened in the atmosphere, and immediately closed after their introduction, the unknown quantities of common air carried in, were always sufficient to render the results perfectly inaccurate.

Animals suffer little or nothing by being passed through water.

That the phenomena in these experiments might be more accurately observed, two or three persons were always present at the time of their execution, and an account of them was noted down immediately after.

a. A stout and healthy young cat, of four or five months old, was introduced into a large jar of nitrous oxide. For ten or twelve moments he remained perfectly quiet, and then began to make violent motions, throwing himself round the jar in every direction. In

two minutes he appeared quite exhausted, and sunk quietly to the bottom of the jar. On applying my hand to the thorax, I found that the heart beat with extreme violence; on feeling about the neck, I could distinctly perceive a strong and quick pulsation of the carotids. In about three minutes the animal revived, and panted very much; but still continued to lie on his side. His inspirations then became longer and deeper, and he sometimes uttered very feeble cries. In four minutes the pulsations of the heart appeared quicker and feebler. His inspirations were at long intervals, and very irregular; in five minutes the pulse was hardly perceptible; he made no motions, and appeared wholly senseless. After five minutes and quarter he was taken out, and exposed to the atmosphere before a warm fire. In a few seconds he began to move, and to take deep inspirations. In five minutes he attempted to rise on his legs; but soon fell again, the extremities being slightly convulsed. In eight or nine minutes he was able to walk, but his motions were staggering and unequal, the right leg being convulsed, whilst the other was apparently stiff and immovable; in about half an hour he was almost completely recovered.

b. A healthy kitten, of about six weeks old, was introduced into nitrous oxide. She very soon began to make violent exertions, and in less than a minute fell to the bottom of the receiver, as if apoplectic. At this moment, applying my hand to her side, I felt the heart beating with great violence. She continued gasping, with long inspirations, for three minutes and half; at the end of five minutes and half she was taken out completely dead.

c. Another kitten of the same breed was introduced into nitrous oxide, the day after. She exhibited the

same phenomena, and died in it in about five minutes and half.

d. A small dog that had accidentally met with a dislocation of the vertebræ of the loins, and was in great pain, as manifested by his moaning and whining, was introduced into a large jar of nitrous oxide. He immediately became quiet, and lay on his side in the jar, breathing very deeply. In four minutes his respiration became noisy, and his eyes sparkled very much. I was not able to apply my hand to the thorax. In five minutes he appeared senseless, and in seven minutes was perfectly dead.

e. A strong rabbit, of ten or twelve months old, was introduced into nitrous oxide. He immediately began to struggle very much, and in a minute fell down senseless: in two minutes the legs became convulsed, and his inspirations were deep and noisy: in less than five minutes he appeared perfectly dead.

f. A rabbit of a month old introduced into nitrous oxide, became senseless in less than a minute; the pulsations of the heart were very strong at this moment: they gradually became weaker, and in three minutes and half the animal was dead.

g. Another rabbit of the same breed, after being rendered senseless in nitrous oxide in a minute and half, was taken out. He soon became convulsed; in a minute began to breathe quickly; in two minutes attempted to rise, but staggered, and fell again on his side. His hinder legs were paralytic for near five minutes. In twenty he had almost recovered.

g. A middle-sized guinea-pig was much convulsed, after being in nitrous oxide for a minute. In two minutes and half he was senseless. Taken out at this period, he remained for some minutes by the side of a

warm fire, without moving; his fore legs then became convulsed; his hind legs were perfectly paralytic. In this state he continued, without attempting to rise or move, for near an hour, when he died.

k. A large and old guinea-pig died in nitrous oxide, exhibiting the same phenomena as the other animals, in about five minutes and quarter. A young one was killed in three minutes and half.

i. A small guinea-pig, after breathing nitrous oxide for a minute and half, was taken out, and placed before a warm fire. He was for a few minutes a little convulsed; but in a quarter of an hour got quite well, and did not relapse.

k. A large mouse introduced into nitrous oxide was for a few seconds very active. In half a minute he fell down senseless; in a minute and quarter he appeared perfectly dead.

l. A mouse taken out of nitrous oxide, after being in it for half a minute, continued convulsed for some minutes, but finally recovered.

m. A young hen was introduced into a vessel filled with nitrous oxide. She immediately began to struggle very much; fell on her breast in less than half a minute, and in two minutes was dead.

n. A goldfinch died in nitrous oxide in less than a minute.

In each of these experiments a certain absorption of the gas was always perceived, the water rising in the jar during the respiration of the animal. From them we learn,

1st. That nitrous oxide is destructive when respired for a certain time to the warm-blooded animals, apparently previously exciting them to a great extent.

2ndly. That when its operation is stopped before

complete exhaustion is brought on, the healthy living action is capable of being gradually reproduced, by enabling the animal to respire atmospheric air.

3dly. That exhaustion and death is produced in the small animals by nitrous oxide sooner than in the larger ones, and in young animals of the same species, in a shorter time than in old ones, as indeed Dr. Beddoes had conjectured *à priori* would be the case.

Most of the animals destroyed in these experiments were examined after death; the appearances in their organs were peculiar. To prevent unnecessary repetitions, an account of them will be given in the fourth section.

III. *Effects of the Respiration of Nitrous Oxide upon Animals, as compared with those produced by their immersion in Hydrogen and Water.*

Before the following experiments were made, a number of circumstances had convinced me that nitrous oxide acted on animals by producing some positive change in their blood, connected with new living action of the irritable and sensitive organs, and terminating in their death.

To ascertain, however, the difference between the effects of this gas and those of hydrogen and non-respirable gases, I proceeded in the following way.

a. Of two healthy rabbits of about two months old, of the same breed, and nearly of the same size,

One was introduced into nitrous oxide. In half a minute, it had fallen down apparently senseless. On applying my hand to the thorax, the action of the heart appeared at first very quick and strong, it gradually

became weaker, and in two minutes and half, the animal was taken out quite dead.

The other was introduced into a jar of pure hydrogen through water. He immediately began to struggle very much, and in a quarter of a minute fell on his side. On feeling the thorax, the pulsations of the heart appeared very quick and feeble, they gradually diminished; his breathing became momentarily shorter, and in rather more than three quarters of a minute, he was taken out dead. Dr. Kinglake was present at this experiment, and afterwards dissected both of the animals.

b. Of two similar rabbits of the same breed, nearly three months old,—One was introduced into nitrous oxide, and after being rendered senseless by the respiration of it for nearly a minute and half, was exposed to the atmosphere, before a warm fire. He recovered gradually, but was occasionally convulsed, and had a paralysis of one of his hinder legs for some minutes: in an hour he was able to walk. The other, after being immersed in hydrogen for near half a minute, was restored to the atmosphere apparently inanimate. In less than a minute he began to breathe, and to utter a feeble noise; in two minutes was able to walk, and in less than three minutes appeared perfectly recovered.

c. A kitten of about two months old was introduced into a jar of nitrous oxide, at the same time that another of the same breed was plunged under a jar of water. They both struggled very much. The animal in the nitrous oxide fell senseless before that under water had ceased to struggle, and to throw out air from its lungs. In two minutes and three quarters, the animal under water was quite dead: it was taken out and exposed to heat and air, but did not shew the slightest signs of life.

At the end of three minutes and half, the animal in nitrous oxide began to gasp, breathing very slowly; at four minutes and three quarters it was yet alive; at the end of five minutes and quarter it appeared perfectly dead. It was taken out, and did not recover.

From these experiments it was evident, that animals lived at least twice as long in nitrous oxide as in hydrogen or water. Consequently from this circumstance alone, there was every reason to suppose that their death in nitrous oxide could not depend on the simple privation of atmospheric air; but that it was owing to some peculiar changes effected in the blood by the gas.

IV. *Of the Changes effected in the Organization of warm-blooded Animals, by the Respiration of Nitrous Oxide.*

The external appearance of animals that have been destroyed in nitrous oxide, is very little different from that of those killed by privation of atmospheric air. The fauces and tongue appear of a dark red, and the eyes are dull, and a little protruded. Their internal organs, however, exhibit a very peculiar change. The lungs are pale brown red, covered here and there with purple spots; the liver is of a very bright red, and the muscular fibre in general dark. Both the auricles and ventricles of the heart are filled with blood. The auricles contract for minutes after the death of the animal. The blood in the left ventricle, and the aorta, is of a tinge between purple and red, whilst that in the right ventricle is of a dark colour, rather more purple than the venous blood. But these appearances, and their causes, will be better understood after the following comparative observations are read.

a. Of two similar rabbits, about eight months old, one, A, was killed by exposure for near six minutes to nitrous oxide, the other, B, was destroyed by a blow on the head.

They were both opened as speedily as possible. The lungs of B were pale, and uniform in their appearance; this organ in A was redder, and every where marked with purple spots. The liver of A was of a dark and bright red, that of B of a pale red brown. The diaphragm of B, when cut, was strongly irritable; that of A rather darker, and scarcely at all contractile. All the cavities of the heart contracted for more than 50 minutes in B. The auricles contracted for near 25 minutes with force and velocity in A: but the ventricles were almost inactive. The vena cava, and the right auricle, in A, were filled with blood, apparently a shade darker than in B. The blood in the left auricle, and the aorta, appeared in A of a purple, a shade brighter than that of the venous blood. In the left auricle of B it was red.

I opened the head of each, but not without injuring the brain, so that I was unable to make any accurate comparison. The colour of the brain in A appeared rather darker than in B.

b. Two rabbits, C and D, were destroyed, C by immersion in nitrous oxide, D in hydrogen: they were both dissected by Dr. Kinglake. The blood in the pulmonary vein and the left auricle of C was of a different tinge from that in D, more inclined to purple red. The membrane of the lungs in C was covered with purple spots, that of D was pale and uniform in its appearance. The brain in C was rather darker than in D; but there was no perceptible effusion of blood into the ventricles either in D or C. The liver

in C was of a brighter red than in health, that in D rather paler.

c. In the last experiment, the comparative irritability of the ventricles and auricles of the heart and the muscular fibre in the two animals, had not been examined. That these circumstances might be noticed, two rabbits, E and F, were killed; E under water in about a minute, and F in nitrous oxide in three minutes. They were immediately opened, and after a minute, the appearance of the heart, and organs of respiration observed.

Both the right and left ventricle of the heart in F contracted but very feebly; the auricles regularly and quickly contracted; the aorta appeared perfectly full of blood. In E, a feeble contraction of the left sinus venosus and auricle was observed; the left ventricle did not contract: the right contracted, but more slowly than in F. In a few minutes, the contractions of the ventricles in F had ceased, whilst the auricles contracted as strongly and quickly as before. The blood in the pulmonary veins of F was rather of a redder purple than in E; the difference of the blood in the vena cava was hardly perceptible, perhaps it was a little more purple in F. The membranous substance of the lungs in F was spotted with purple as from extravasated blood, whilst that in E was pale. The brain in F was darker than in E. On opening the ventricles no extravasation of blood was perceptible. The auricles of the heart in F contracted strongly for twenty minutes, and then gradually their motion became less frequent; in twenty-eight minutes it had wholly ceased. The right auricle and ventricle in E, occasionally contracted for half an hour. The livers of both animals were similar when they were first opened, of a dark red; that of F

preserved its colour for some time when exposed to the atmosphere ; whilst that of E almost immediately became paler under the same circumstances.

The peristaltic motion continued for nearly an equal time in both animals.

d. The sternum of a young rabbit was removed so that the heart and lungs could be perceived, and he was introduced into a vessel filled with nitrous oxide ; the blood in the pulmonary veins gradually became more purple, and the heart appeared to beat quicker than before, all the muscles contracting with great force. After he had been in about a minute, spots began to appear on the lungs, though the contractions of the heart became quicker and weaker ; in three minutes and a half he was quite dead ; after death the ventricles contracted very feebly, though the contractions of the auricles were as strong almost after the end of five minutes as at first. This animal was passed through water saturated with nitrous oxide ; possibly this fluid had some effect on his organs.

Besides these animals, many others, as guinea-pigs, mice and birds, were dissected after being destroyed in nitrous oxide ; in all of them the same general appearance was observed. Their muscular fibre almost always appeared less irritable than that of animals destroyed by organic lesion of part of the nervous system, in the atmosphere. The ventricles of the heart in general, contracted feebly and for a very short time ; whilst the auricles continued to act for a great length of time. The lungs were dark in their appearance, and always suffused here and there with purple ; the blood in the pulmonary veins when slightly observed, appeared dark, like venous blood, but when minutely examined, was evidently much more purple. The blood in the vena

cava was darker than that in the pulmonary veins. The cerebrum was dark.

In a late experiment, I thought I perceived a slight extravasation of blood in one of the ventricles of the brain in a rabbit destroyed in nitrous oxide; but as this appearance had not occurred in the animals I had examined before, or in those dissected by Dr. Kinglake, and Mr. King, surgeon, I am inclined to refer it to an accidental cause. At my request, Mr. Smith, surgeon, examined the brain of a young rabbit that had been killed in his presence in nitrous oxide; he was of opinion that no effusion of blood into the ventricles had taken place.

In comparing the external appearance of the crural nerves in two rabbits that had been dissected by Dr. Kinglake, having been destroyed, one in hydrogen, the other in nitrous oxide, we could perceive no perceptible difference.

It deserves to be noticed, that whenever the gall bladder and the urinary bladder have been examined in animals destroyed in nitrous oxide, they have been always distended with fluid; which is hardly ever the case in animals killed by privation of atmospheric air.

In the infancy of my experiments on the action of nitrous oxide upon animals, I thought that it rendered the venous blood less coagulable; but this I now find to be a mistake. The blood from the pulmonary veins of animals killed in nitrous oxide, does not sensibly differ in this respect from the arterial blood of those destroyed in hydrogen, and both become vermillion nearly in the same time when exposed to the atmosphere.

In describing the various shades of colour of the blood in the preceding observations on the different

dissected animals, the poverty of the language of colour has obliged me to adopt terms, which I fear will hardly convey to the mind of the reader, distinct notions of the differences observable by minute examination in the venous and arterial blood of animals that die of privation of atmospheric air, and of those destroyed by the action of nitrous oxide. This difference can only be observed in the vessels by means of a strong light; it may, however, be easily noticed in the fluid blood by the introduction of it from the arteries or veins at the moment of their incision, between two polished surfaces of white glass,* so closely adapted to each other, as to prevent the blood from coming in contact with the atmosphere.

Having four or five times had an opportunity of bleeding people in the arm for trifling complaints, I have always received the blood in phials, filled with various gases, in a mode to be described hereafter. Venous blood agitated in nitrous oxide, compared with similar blood in common air, hydrogen, and nitrogen, was always darker and more purple than the first, and much brighter and more florid than the two last, which were not different in their colour from venous blood, received between two surfaces of glass. It will be seen hereafter, that the coagulum of venous blood is rendered more purple when exposed to nitrous oxide, whilst the gas is absorbed; likewise that blood altered by nitrous oxide is capable of being again rendered vermilion, by exposure to the air.

The appearances noticed in the above-mentioned experiments, in the lungs of animals destroyed in

* The colour of common venous blood, examined in this way, resembles that of the paint called by colour-men red ochre; that of blood saturated with nitrous oxide, approaches to the tinge of lake.

nitrous oxide, are similar to those observed by Dr. Beddoes, in animals that had been made to breathe oxygen for a great length of time.

There were many reasons for supposing that the large purple spots in the lungs of animals destroyed in nitrous oxide, were owing to extravasation of venous blood from the capillary vessels; their coats being broken by the highly increased arterial action. To ascertain whether these phenomena existed at a period of the action of nitrous oxide, when the animal was recoverable by exposure to the atmosphere,

I introduced a rabbit of six months old, into a vessel of nitrous oxide, and after a minute, when it had fallen down apparently apoplectic, plunged him wholly under water; he immediately began to struggle, and what surprised me very much, died in less than a minute after submersion. On opening the thorax, the blood in the pulmonary veins was nearly of the colour of that in animals that have been simply drowned. The lungs were here and there marked with a few points; but there were no large purple spots, as in animals that have been wholly destroyed in nitrous oxide: the right side of the heart only contracted. In this experiment, the excitement from the action of the gas was probably carried to such an extent, as to produce indirect debility. There are reasons for supposing, that animals, after having been excited to but a small extent by the respiration of nitrous oxide, will live under water for a greater length of time than animals previously made to breathe common air.

V. Of the Respiration of Mixtures of Nitrous Oxide, and other Gases, by warm-blooded Animals.

a. A rabbit of near two months old, was introduced

into a mixture of equal parts hydrogen and nitrous oxide through water. He immediately began to struggle; in a minute fell on his side; in three minutes gasped, and made long inspirations; and in four minutes and half, was dead. On dissection, he exhibited the same appearances as animals destroyed in nitrous oxide.

b. A large and strong mouse was introduced into a mixture of three parts hydrogen to one part nitrous oxide. He immediately began to struggle very much, in half a minute became convulsed, and in about a minute was quite dead.

c. Into a mixture of one oxygen, and three nitrous oxide, a small guinea-pig was introduced. He immediately began to struggle, and in two minutes reposed on his side, breathing very deeply. He made afterwards no violent muscular motion; but lived quietly for near fourteen minutes: at the end of which time his legs were much convulsed. He was taken out, and recovered.

d. A mouse lived apparently without suffering, for near ten minutes, in a mixture of 1 atmospheric air, and 3 nitrous oxide, at the end of eleven minutes he began to struggle, and in thirteen minutes became much convulsed.

e. A cat of three months old, lived for seventeen minutes, in a very large quantity of a mixture of 1 atmospheric air, and 12 nitrous oxide. On her first introduction she was very much agitated and convulsed, in a minute and half she fell down as if apoplectic, and continued breathing very deeply during the remainder of the time, sometimes uttering very feeble cries. When taken out she appeared almost inanimate, but on being laid before the fire, gradually began to breathe and move; being for some time, like most of the animals

that have recovered after breathing nitrous oxide, convulsed on one side, and paralytic the other.

f. A goldfinch lived for near five minutes in a mixture of equal parts, nitrous oxide and oxygen, without apparently suffering. Taken out, he appeared faint and languid, but finally recovered.*

VI. *Recapitulation of Facts relating to the Respiration of Nitrous Oxide, by warm-blooded Animals.*

1. Warm-blooded animals die in nitrous oxide infinitely sooner than in common air or oxygen; but not nearly in so short a time as in gases incapable of effecting positive changes in the venous blood, or in non-respirable gases.

2. The larger animals live longer in nitrous oxide than the smaller ones, and young animals die in it sooner than old ones of the same species.

3. When animals, after breathing nitrous oxide, are removed from it before complete exhaustion has taken place, they are capable of being restored to health under the action of atmospheric air.

4. Peculiar changes are effected in the organs of animals by the respiration of nitrous oxide. In animals destroyed by it, the arterial blood is purple red, the lungs are covered with purple spots, both the hollow and compact muscles are *apparently* very inirritable, and the brain is dark-coloured.

5. Animals are destroyed by the respiration of mixtures of nitrous oxide and hydrogen nearly in the same

* Small birds suffer much from cold when introduced into gases through water. In this experiment, the goldfinch was immediately inserted into a large-mouthed phial, filled with the gases, and opened in the atmosphere.

time as by pure nitrous oxide ; they are capable of living for a great length of time in nitrous oxide mingled with very minute quantities of oxygen or common air.

These facts will be reasoned upon in the next Division.

VII. *Of the Respiration of Nitrous Oxide by Amphibious Animals.*

As from the foregoing experiments, it appeared that the nitrous oxide destroyed warm-blooded animals by increasing the living actions of their organs to such an extent, as finally to exhaust their irritability and sensibility ; it was reasonable to conjecture that the cold-blooded animals, possessed of voluntary power over respiration, would so regulate the quantity of nitrous oxide applied to the blood in their lungs as to bear its action for a great length of time. This conjecture was put to the test of experiment ; the following facts will prove its error.

a. Of two middle-sized water-lizards, one was introduced into a small jar filled with nitrous oxide, over moist mercury, by being passed through the mercury ; the other was made to breathe hydrogen, by being carried into it in the same manner.

The lizard in nitrous oxide, in two or three minutes, began to make violent motions, appeared very uneasy, and rolled about the jar in every direction, sometimes attempting to climb to the top of it. The animal in hydrogen was all this time very quiet, and crawled about the vessel without being apparently much affected. At the end of twelve minutes, the lizard in nitrous oxide was lying on his back, seemingly dead ; but on agitating the jar he moved a little ; at the end of fifteen minutes

he did not move on agitation, and his paws were resting on his belly. He was now taken out stiff, and apparently lifeless, but after being exposed to the atmosphere for three or four minutes, took an inspiration, and moved his head a little; he then raised the end of his tail, though the middle of it was still stiff, and did not bend when touched. His legs remained close to his side, and were apparently useless; but on pricking them with the point of a lancet, they became convulsed. After being introduced into shallow water, he was able to crawl in a quarter of an hour, though his motions were very irregular. In an hour he was quite well. The animal in hydrogen appeared to have suffered very little in three quarters of an hour, and had raised himself against the side of the jar. At the end of an hour he was taken out, and very soon recovered.

b. Some hours after, the same lizards were again experimented upon. That which had been inserted into hydrogen in the last experiment, being now inserted into nitrous oxide.

This lizard was apparently lifeless in fourteen minutes, having tumbled and writhed himself very much during the first ten minutes. Taken out after being in twenty-five minutes, he did not recover. The other lizard lived in hydrogen for near an hour and quarter; taken out after an hour and twenty minutes, he was dead.

These animals were both opened, but the viscera of the nitrous oxide lizard were so much injured by the knife, that no accurate comparison of them with those of the other could be made, I thought that the lungs appeared rather redder.

c. Of two similar large water-lizards, one was introduced into a vessel standing over mercury, wholly filled

with water that had been long boiled and suffered to cool under mercury.

The animal very often rose to the top of the jar, as if in search of air, during the first half hour; but shewed no other signs of uneasiness. At the end of three quarters of an hour, he became very weak, and appeared scarcely able to swim in the water. Taken out at the end of fifty minutes, he recovered.

The other was inserted into nitrous oxide. After much struggling, he became senseless in about fifteen minutes, and lay on his back. Taken out at the end of twenty minutes, he remained for a long time motionless and stiff, but in a quarter of an hour began to move some of his limbs.

From these experiments, we may conclude, that water-lizards, and most probably the other amphibious animals, die in nitrous oxide in a much shorter time than in hydrogen or pure water; consequently their death in it cannot depend on the simple privation of atmospheric air.

At the season of the year in which this investigation was carried on, I was unable to procure frogs or toads. This I regret very much.

Supposing that cold-blooded animals die in nitrous oxide from positive changes effected in their blood by the gas, it would be extremely interesting to notice the apparent alterations taking place in their organs of respiration and circulation during its action, which could easily be done, the membranous substance of their lungs being transparent. The increase or diminution of the irritability of their muscular fibre, might be determined by comparative galvanic experiments.

VIII. *Effects of Solution of Nitrous Oxide in Water on Fishes.*

a. A small flounder was introduced into a vessel filled with solution of nitrous oxide in water over mercury. He remained at rest for ten minutes and then began to move about the jar in different directions. In half an hour he was apparently dying, lying on his side in the water. He was now taken out, and introduced into a vessel filled with water saturated with common air, he very soon recovered.

b. Of two large thornbacks,* equally brisk and lively. One, A, was introduced into a jar containing nearly 3 cubic inches of water, saturated with nitrous oxide, and which previous to its impregnation had been long boiled; the other, B, was introduced into an equal quantity of water which had been deprived of air by distillation through mercury.

A, appeared very quiet for two or three minutes, and then began to move up and down in the jar, as if agitated. In eight minutes his motions became very irregular, and he darted obliquely from one side of the jar to the other. In twelve minutes, he became still, and moved his gills very slowly. In fifteen minutes he appeared dead. After fifteen minutes he was taken out, but shewed no signs of life.

B was very quiet for four minutes and half. He then began to move about the jar. In seven minutes he had fallen on his back, but still continued to move his gills. In eleven minutes he was motionless; taken out after thirteen minutes, he did not recover.

* I use the popular name. This fish is very common in every part of England; it is nearly of the same size and colour as the minnow, and is distinguished from it by two small bony excrescences at the origin of the belly. It is extremely susceptible.

c. Of two thornbacks, one, C, was introduced into about an ounce of boiled water in contact with hydrogen, standing over mercury. The other, D, was introduced into well boiled water saturated with nitrous oxide, and standing in contact with it over mercury. C lived near thirteen minutes, and died without being previously much agitated. D was apparently motionless, after having the same affections as A in the last experiment, in sixteen minutes. At the end of this time he was taken out and introduced into common water. He soon began to move his gills, and in less than a quarter of an hour was so far recovered as to be able to swim.

The last experiment was repeated on two small thornbacks; that in the aqueous solution of nitrous oxide lived near seventeen minutes, that in the water in contact with hydrogen, about fifteen and half.

The experiments in Res. I. Div. III. prove the difficulty, and indeed almost impossibility of driving from water by boiling, the whole of the atmospheric air held in solution by it; they likewise show that nitrous oxide by its strong affinity for water, is capable of expelling air from that fluid after no more can be procured from it by ebullition.

Hence, if water saturated without nitrous oxide had no positive effects upon fishes, they ought to die in it much sooner than in water deprived of air by ebullition. From their living in it rather longer;* we may conclude, that they are destroyed not by privation of atmospheric air, but from some positive change effected in their blood by the gas.

A long while ago, from observing that the gills of

* *A priori* I expected that fishes, like amphibious animals, would have been very quickly destroyed by the action of nitrous oxide.

fish became rather of a lighter red during their death, in the atmosphere, I conjectured that the disease of which they died, was probably hyperoxygenation of the blood connected with highly increased animal heat. For not only is oxygen presented to their blood in much larger quantities in atmospheric air than in its aqueous solution; but likewise, to use common language, in a state in which it contains much more *latent heat*. Without however laying any stress on this supposition, I had the curiosity to try whether thornbacks would live longest in atmospheric air or nitrous oxide. In one experiment, they appeared to die in them nearly in the same time. In another, the fish in nitrous oxide lived nearly half as long again as that in atmospheric air.

XI. *Effects of Nitrous Oxide on Insects.*

The winged insects furnished with breathing holes, become motionless in nitrous oxide very speedily; being however possessed of a certain voluntary power over respiration, they sometimes recover, after having been exposed to it for some minutes under the action of atmospheric air.

A butterfly was introduced into a small jar, filled with pure nitrous oxide, over mercury. He struggled a little during the first two or three seconds; in about seven seconds, his legs became convulsed, and his wings were wrapt round his body; in about half a minute he was senseless; taken out after six minutes; he did not recover.

Another butterfly introduced into hydrogen, became convulsed in about a quarter of a minute, was senseless in twenty seconds, and taken out after five minutes, did not revive.

A large drone, after being in nitrous oxide for a minute and a quarter, was taken out senseless. After being for some time exposed to the atmosphere, he began to move, and at last rose on his wings. For some time, however, he was unable to fly in a straight line; and often after describing circles in the air, fell to the ground as if giddy.

A large fly became motionless in nitrous oxide after being convulsed, in about half a minute. Another was rendered senseless in hydrogen, in less than a quarter of a minute.

A fly introduced into hydro-carbonate, dropped immediately senseless; taken out after about a quarter of a minute, he recovered; but like the fly that had lived after exposure to nitrous oxide, was for some time vertiginous.

Flies live much longer under water, alcohol, or oil, than in non-respirable gases, or gases incapable of supporting life. A certain quantity of air always continues attached in the fluid to the fine hairs surrounding their breathing holes, sufficient to support life for a short time.

Snails and earth-worms live in nitrous oxide a long while; they die in it, however, much sooner than in water or hydrogen; probably from the same causes as the amphibious animals.

DIVISION II.

OF THE CHANGES EFFECTED IN NITROUS OXIDE, AND OTHER GASES, BY THE RESPIRATION OF ANIMALS.

I. *Preliminaries.*

As soon as I had discovered that nitrous oxide was respirable, and possessed of extraordinary powers of

action on living beings, I was anxious to be acquainted with the changes effected in it by the venous blood. To investigate these changes, appeared at first a simple problem; I soon however found that it involved much preliminary knowledge of the chemical properties and affinities of nitrous oxide. After I had ascertained by experiments detailed in the preceding Researches, the composition of this gas, its combinations, and the physical changes effected by it in living beings, I began my inquiry relating to the mode of its operation.

Finding that the residual gas of nitrous oxide, after it had been breathed for some time in silk bags, was chiefly nitrogen, I at first conjectured that nitrous oxide was decomposed in respiration in the same manner as atmospheric air, and its oxygen only combined with the venous blood; the following experiments soon however convinced me of my error.

II. *Absorption of Nitrous Oxide by Venous Blood.* *Changes effected in the Blood by different Gases.*

a. Though the laws of the coagulability of the blood are unknown, yet we are certain that at the moment of coagulation, a perfectly new arrangement of its principles take place; consequently, their powers of combination must be newly modified. The affinities of living blood can only be ascertained during its circulation in the vessels of animals. At the moment of effusion from those vessels, it begins to pass through a series of changes, which first produce coagulation, and finally its complete decomposition.

Consequently, the action of fluid blood upon gases out of the vessels will be more analogous to that of circulating blood in proportion as it is more speedily placed in contact with them.

b. To ascertain the changes effected in nitrous oxide by fluid venous blood,

A jar, six inches long and half an inch wide, graduated to .05 cubic inch, having a tight stopper adapted to it, was filled with nitrogen, which is a gas incapable of combining with, and possessing no power of action upon venous blood. A large orifice was made in the vein of a tolerably healthy man, and the stopper removed from the jar, which was brought in contact with the arm so as to receive the blood, and pressed close against the skin, in such a way as to leave an orifice just sufficient for the escape of the nitrogen, as the blood flowed in. When the jar was full, it was closed, and carried to the pneumatic apparatus, the mercury of which had been previously a little warmed. A small quantity of the blood was transferred into another jar to make room for the gas. The remaining quantity equalled exactly two cubic inches; to this was introduced as speedily as possible, eleven measures equal to .55 cubic inch of nitrous oxide, which left a residuum of $\frac{1}{3}\frac{1}{2}$ only, when absorbed by boiled water, and was consequently perfectly pure. On agitation, a rapid diminution of the gas took place.

In the mass of blood, which was opaque, but little change of colour could be perceived; but that portion of it diffused over the sides of the jar, was evidently of a brighter purple than the venous blood.

It was agitated for two or three minutes, and then suffered to rest; in eight minutes it had wholly coagulated; a small quantity of serum had separated, and was diffused over the coagulum. This coagulum was dark; but evidently of a more purple tinge than that of venous blood; no gas had apparently been liberated during its formation.

The nitrous oxide remaining was not quite equal to seven measures; hence, at least four measures of it had been absorbed.

To ascertain the nature of the residuum, it was necessary to transfer it into another vessel, but this I found very difficult to accomplish, on account of the coagulated blood. By piercing through the coagulum, and removing part of it by means of curved iron forceps, I at last contrived to introduce about $4\frac{1}{2}$ measures of the gas into a small cylinder, graduated to .25 cubic inch, in which it occupied, of course, nearly 9 measures; when a little solution of strontian was admitted to these, it became very slightly clouded; but the absorption that took place did not more than equal half its bulk. Consequently, the quantity of carbonic acid evolved from the blood, or formed, must have been extremely minute.

On the introduction of pure water, a rapid absorption of the gas took place, and after agitation, not quite 3 measures remained. These did not *perceptibly* diminish with nitrous gas; their quantity was too small to be examined by any other test; but there is reason to suppose that they were chiefly composed of nitrogen.

From this experiment, it appeared that nitrous oxide is absorbed, when placed in contact with venous blood; at the same time that a very minute quantity of carbonic acid and probably nitrogen is produced.

c. In another similar experiment when nearly half a cubic inch of nitrous oxide was absorbed by about a cubic inch and three quarters of fluid blood, the residual gas did not equal more than $\frac{1}{8}$, the quantity absorbed being taken as unity. This fact induced me to suppose that the absorption of nitrous oxide by venous blood

was owing to a simple solution of the gas in that fluid, analogous to its solution in water or alcohol.*

To ascertain if nitrous oxide could be expelled from blood impregnated with it, by heat, I introduced to 2 cubic inches of fluid blood taken from the medial vein, about $\cdot 6$ cubic inch of nitrous oxide. After agitation, in seven minutes, nearly $\cdot 4$ were absorbed. In ten minutes, after the blood had completely coagulated, the cylinder containing it, was transferred in contact with mercury, into a vessel of solution of salt in water; this solution was heated and made to boil. During its ebullition, the whole of the blood became either white or pale brown, and formed a solid coherent mass; whilst small globules of gas were given out from it. In a few minutes, about $\cdot 25$ of gas had collected. After the vessel had cooled, I attempted to transfer this gas into a small graduated jar in the mercurial apparatus, but in vain; the mass in the jar was so solid and tough, that I could not remove it. By transferring it to the water apparatus, I succeeded in displacing enough of the coagulum to suffer the water to come in contact with the gas; an absorption of nearly half of it took place; hence, *I conjecture*, that nitrous oxide had been given out by the impregnated blood.

d. Some fresh dark coagulum of venous blood was exposed to nitrous oxide. A very slight alteration of colour took place at the surface of the blood, perceptible only in a strong light, and a minute quantity of gas was absorbed. A taper burnt in the remaining gas as bril-

* [According to my experiments, venous and arterial blood, deprived of fibrin and the serum of blood, absorb equally nitrous oxide, and in about the same proportion as water, viz. about 68·5 per cent. over mercury, at 45° Fah.—Vide Phil. Trans. for 1838, p. 295.]

liantly as before; hence, it had apparently suffered no alteration.

e. To compare the physical changes effected in the venous blood by nitrous oxide, with those produced by other gases, I made the following experiments.—I filled a large phial, containing near 14 cubic inches, with blood from the vein of the arm of a man, and immediately transferred it to the mercurial apparatus. Different portions of it were thrown into small graduated cylinders, filled with the following gases; nitrogen, nitrous gas, common air, oxygen, nitrous oxide, carbonic acid, and hydrocarbonate.

The blood in each of them was successively agitated till it began to coagulate; and making allowances for the different periods of agitation, there was no marked difference in the times of coagulation.

The colour of the coagulum in every part of the cylinder, containing nitrogen, was the same very dark red. When it was agitated so as to tinge the sides of the jar, it appeared exactly of the colour of venous blood received between two surfaces of glass; no perceptible absorption of the gas had taken place.

The blood in nitrous gas was dark, and much more purple on the top than that in nitrogen. When agitated so as to adhere to the jar as a thin surface, this purple was evidently deep and bright. An absorption of rather more than $\frac{1}{8}$ of the volume of gas had taken place.*

The blood in oxygen and atmospheric air, were of a much brighter tinge than that in any of the other gases.

* [I have found the arterial blood of the sheep, its fibrin separated, absorb 32 per cent. of nitrous gas, and venous blood 19 per cent.—Phil. Trans. 1838, p. 296.]

On the top, the colour was vermilion, but no perceptible absorption had taken place.*

The coagulum in nitrous oxide, when examined in the mass was dark, and hardly distinguishable in its colour from venous blood; but when minutely noticed at the surface where it was covered with serum, and in its diffusion over the sides of the jar, it appeared of a fine purple-red, a tinge brighter than the blood in nitrous gas. An absorption had taken place in this cylinder, more considerable than in any of the others.

In carbonic acid, the coagulum was of a brown red, much darker than the venous blood, and a slight diminution of gas had taken place.†

In the hydrocarbonate,‡ the blood was red, a shade darker than the oxygenated blood, and a very slight diminution of the gas§ was perceptible.

f. To human blood that had been saturated with nitrous oxide whilst warm and constantly agitated for four or five minutes, to prevent its uniform coagulation, oxygen was introduced; the red purple on the surface of it immediately changed to vermilion; and on agitation, this colour was diffused through it. On comparing the tinge with that of oxygenated blood, no perceptible

* [According to the latest and most careful inquiries, when blood is agitated either in oxygen gas or common air, a portion of oxygen is absorbed, and in the instance of venous blood greater than that of arterial.]

† [Both venous and arterial blood I find are capable of absorbing carbonic acid gas largely,—more than their own volume, about 150 per cent.—Phil. Trans. 1838, p. 287.]

‡ The hydrocarbonate employed was procured from alcohol, by means of sulphuric acid. This gas contains more carbon, than hydrocarbonate from water and charcoal.

§ The curious fact of the reddening of venous blood by hydrocarbonate was discovered by Dr. Beddoes.

difference could be observed. No change of volume of the oxygen introduced, had taken place; and consequently, no nitrous oxide had been evolved from the blood.

g. Blood, impregnated with nitrous gas, was exposed to oxygen; but after agitation in it for many minutes, no change of its dark purple tinge could be observed, though a slight diminution of the oxygen appeared to take place.

h. Blood that had been rendered vermilion in every part by long agitation in atmospheric air, the coagulum of which was broken and diffused with the coagulable lymph through the serum, was exposed to nitrous oxide; for some minutes no perceptible change of colour took place; but by agitation for two or three hours, it evidently assumed a purple tinge, whilst a slight absorption of gas took place. It never, however, became nearly so dark as venous blood that had been exposed to nitrous oxide.

i. Blood, oxygenated in the same manner as in the last experiment, the coagulum of which had been broken, was exposed to nitrous gas. The surface of it immediately became purple, and by agitation for a few minutes, this colour was diffused through it. A slight diminution of the gas was observed. On comparing the tinge with that of venous blood that had been previously exposed to nitrous gas, there was no perceptible difference.

k. Blood exposed to oxygenated muriatic acid is wholly altered in its constitution and physical properties, as has been often noticed; the coagulum becomes black in some parts, and brown and white in others. Venous blood, after agitation in hydrogen or nitrogen, oxygenates when exposed to the atmosphere in the

same manner as simple venous blood. I had the curiosity to try whether venous blood exposed to hydrogen would retain its power of being oxygenated longer than blood saturated with nitrous oxide: for this purpose some similar black coagulum was agitated for some time in two phials, one filled with hydrogen, the other with nitrous oxide. They were then suffered to rest for three days at a temperature from about 56° to 63° . After being opened, no offensive smell was perceived in either of them, the blood in hydrogen was rather darker than at the time of their exposure, whilst that in nitrous oxide was of a brighter purple. On being agitated for some time in the atmosphere, the blood in nitrous oxide became red, but not of so bright a tinge as oxygenated venous blood. The colour of the blood in hydrogen did not at all alter.

l. To ascertain whether impregnation with nitrous oxide accelerated or retarded the putrefaction of the blood; I exposed venous blood in four phials, the first filled with hydrocarbonate, the second with hydrogen; the third with atmospheric air, and the fourth with nitrous oxide. Examined after a fortnight, the blood in hydrogen and common air were both black, and stunk very much; that in hydrocarbonate was red, and perfectly sweet; that in nitrous oxide appeared purple, and had no disagreeable smell.

In a second experiment, when blood was exposed for three weeks to hydrocarbonate and nitrous oxide, that in nitrous oxide was darker than before and stunk a little; that in hydrocarbonate was still perfectly sweet. The power of hydrocarbonate to prevent the putrefaction of animal matters, was long ago noticed by Mr. Watt.

m. Having accidentally cut one of my fingers so as to

lay bare a little muscular fibre, I introduced it whilst bleeding into a bottle of nitrous oxide; the blood that trickled from the wound evidently became much more purple; but the pain was neither alleviated nor increased. When, however, the finger was taken out of the nitrous oxide, and exposed to the atmosphere, the wound smarted more than it had done before. After it had ceased to bleed, I inserted it through water into a vessel of nitrous gas; but it did not become more painful than before.

From all these observations we may conclude,

1st. That when nitrous oxide is agitated in fluid venous blood, a certain portion of the gas is absorbed; whilst the colour of the blood changes from dark red to red purple.

2dly. That during the absorption of nitrous oxide by the venous blood, minute portions of nitrogen and carbonic acid are produced, either by evolution from the blood, or from a decomposition of part of the nitrous oxide.

3dly. That venous blood impregnated with nitrous oxide is capable of oxygenation; and *vice versâ*; that oxygenated blood may be combined with nitrous oxide.

When blood separated into coagulum and serum, is exposed to nitrous oxide, it is most probable that the gas is chiefly absorbed by the serum. That nitrous oxide, however, is capable of acting upon the coagulum, is evident from *d*. In the fluid blood, as we shall see hereafter, nitrous oxide is absorbed by the attractions of the whole compound.

III. *Of the Changes effected in Nitrous Oxide by Respiration.*

To ascertain whether the changes effected in nitrous oxide by the circulating blood acting through the moist coats of the pulmonary veins of living animals, were highly analogous to those produced in it by fluid venous blood removed from the vessels, I found extremely difficult.

I have before observed, that when animals are made to respire nitrous oxide, a certain absorption of the gas always takes place; but the smaller animals, the only ones that can be experimented upon in the mercurial apparatus, die in nitrous oxide so speedily and occasion so slight a diminution of gas, that I judged it useless to attempt to analyze the residuum of their respiration, which supports flame as well as pure nitrous oxide, and is chiefly absorbable by water.

In the infancy of my researches, I often respired nitrous oxide in a large glass bell, furnished with a breathing tube and stop-cock, and poised in water saturated with the gas.

In two or three experiments in which the nostrils being closed after the exhaustion of the lungs, the gas was inspired from the bell and respired into it, a considerable diminution was perceived, and by the test of lime-water some carbonic acid appeared to have been formed; but on account of the absorption of this carbonic acid by the impregnated water, and the liberation of nitrous oxide from it, it was impossible to determine with the least accuracy, the quantities of products after respiration.

About this time likewise, I often examined the residuum of nitrous oxide, after it had been respired in silk bags. In these experiments when the gas had been breathed for a long time, a considerable diminution of it was observed, and the remainder extinguished flame, and gave a very slight diminution with nitrous gas. But the great quantity of this remainder as well as other phenomena, convinced me that though the oiled silk was apparently air-tight when dry, under slight pressure, yet during the action of respiration, the moist and warm gas expired, penetrated through it, whilst common air entered through the wetted surface.

To ascertain accurately the changes effected in nitrous oxide by respiration, I was obliged to make use of the large mercurial air-holder mentioned in Research I. of the capacity of 200 cubic inches. The upper cylinder of it was accurately balanced so as to be constantly under the pressure of the atmosphere. To an aperture in it, a stop-cock having a very large orifice was adapted, curved and flattened at its upper extremity, so as to form an air-tight mouth-piece.

By accurately closing the nose, and bringing the lips tight on the mouth-piece, after a few trials I was able to breathe oxygen or common air in this machine for two minutes or two minutes and a half, without any other uneasy feeling than that produced by the inclination of the neck and chest towards the cylinder. The power of uniformly exhausting the lungs and fauces to the same extent, I did not acquire till after many experiments. At last, by preserving exactly the same posture after exhaustion of the lungs before the inspiration of the gas to be experimented upon, and during its complete expiration, I found that I could always retain nearly the same quantity of gas in the bronchial vessels

and fauces; the difference in the volume expired at different times, never amounting to a cubic inch and a half.

By connecting the conducting pipe of the mercurial air-holder, during the respiration of the gas, with a small trough of mercury by means of a curved tube, it became a perfect and excellent breathing machine. For by exerting a certain pressure on the air-holding cylinder, it was easy to throw a quantity of gas after every inspiration or expiration, into tubes filled with mercury standing in the trough. In these tubes it could be accurately analyzed, and thus the changes taking place at different periods of the process ascertained.

Whenever I breathed pure nitrous oxide in the mercurial air-holder, after a complete voluntary exhaustion of my lungs, the pleasurable delirium was very rapidly produced, and being obliged to stoop on the cylinder, the determination of blood to my head from the increased arterial action in less than a minute became so great, as often to deprive me of voluntary power over the muscles of the mouth. Hence, I could never rely on the accuracy of any experiment, in which the gas had been respired for more than three-quarters of a minute.

I was able to respire the gas with great accuracy for more than half a minute; it at first, rather increasing than diminishing the power of volition; but even in this short time, very strong sensations were always produced, with sense of fulness about the head, somewhat alarming: a feeling which hardly ever occurs to me when the gas is breathed in the natural posture.

In all the numerous experiments that I made on the respiration of nitrous oxide in this way, a very considerable diminution of gas always took place; and the

diminution was generally apparently greater to the eye during the first four or five inspirations.

The residual gas of an experiment was always examined in the following manner. After being transferred through mercury into a graduated cylinder, a small quantity of concentrated solution of caustic potash was introduced to it, and suffered to remain in contact with it for some hours; the diminution was then noted, and the quantity of gas absorbed by the potash, judged to be carbonic acid. To the remainder, twice its bulk of pure water was admitted. After agitation and rest for four or five hours, the absorption by this was noticed, and the gas absorbed considered as nitrous oxide. The residual unabsorbable gas was mingled over water with twice its bulk of nitrous gas; and by this means, its composition, whether it consisted wholly of nitrogen, or of nitrogen mingled with small quantities of oxygen, ascertained.

From a number of experiments made at different times on the respiration of nitrous oxide, I select the following as the most accurate.

E. 1. At temperature 54° , I breathed 102 cubic inches of nitrous oxide, which contained near $\frac{1}{30}$ common air, for about half a minute, seven inspirations and seven expirations being made. After every expiration, an evident diminution of gas was perceived; and when the last full expiration was made, it filled a space equal to 62 cubic inches.

These 62 cubic inches analyzed, were found to consist of

Carbonic acid	.	.	.	3.2
Nitrous oxide	.	.	.	29.0
Oxygen	.	.	.	4.1
Nitrogen	.	.	.	<u>25.7</u>
				62.0

Hence, accounting for the two cubic inches of common air previously mingled with the nitrous oxide, 71 cubic inches had disappeared in this experiment.

In the last respirations, the quantity of gas was so much diminished, as to prevent the full expansion of the lungs; and hence the apparent diminution was very much less after the first four inspirations.

E. 2. At temperature 47°, I breathed 182 cubic inches of nitrous oxide, mingled with $2\frac{1}{2}$ cubic inches of atmospheric air, which previously existed in the air-holder, for near 40 seconds; having in this time made 8 respirations. The diminution after the first full inspiration, appeared to a by-stander nearly uniform. When the last complete expiration was made, the gas filled a space equal to 128 cubic inches, the common temperature being restored. These 128 cubic inches analyzed, were found to consist of

Carbonic acid	.	.	.	5.25
Nitrous oxide	.	.	.	88.75
Oxygen	.	.	.	5.00
Nitrogen	.	.	.	29.00

Consequently, in this experiment, 93.25 cubic inches of nitrous oxide had disappeared.

In each of these experiments, the cylinder was covered with condensed watery vapour exactly in the same manner as if common air had been breathed in it. It ought to be observed that, *E. 1.* was made in the morning, four hours and a-half after a moderate breakfast; whereas, *E. 2.* was made but an hour and a-quarter after a plentiful dinner; at which near three-fourths of a pint of table-beer had been drank.

From these experiments we learn, that nitrous oxide is rapidly absorbed by the venous blood, through the moist coats of the pulmonary veins. But as after a

complete voluntary exhaustion of the lungs, much residual air must remain in the bronchial vessels and fauces, as appears from their incapability of completely collapsing, it is evident that the gas expired after every inspiration of nitrous oxide must be mingled with different quantities of the residual gas of the lungs;* whilst after a complete expiration, much of the unabsorbed nitrous oxide must remain as residual gas in the lungs. Now when a complete expiration is made after the breathing of atmospheric air, it is evident that the residual gas of the lungs consists of nitrogen,† mingled with small portions of oxygen and carbonic acid. And these are the only products found after the respiration of nitrous oxide.

To ascertain whether these products were partially produced, during the process of respiration, as I was inclined to believe from the experiments in the last section, or whether they were wholly the residual gases of the lungs, I found extremely difficult.

I at first thought of breathing nitrous oxide immediately after my lungs had been filled with oxygen; and to compare the products remaining after the full expiration, with those produced after a full expiration of pure oxygen; but on the supposition that oxygen and nitrous oxide, when applied together to the venous blood, must effect changes in it different from either of them separately, the idea was relinquished.

I attempted to inspire nitrous oxide, after having made two inspirations and a complete expiration of hydrogen; but in this experiment the effects of the hydrogen were so debilitating, and the consequent sti-

* By lungs, I mean in this place, all the internal organs of respiration.

† Because these products are formed during the respiration of common air.

mulation by the nitrous oxide so great, as to deprive me of sense. After the first three inspirations, I lost all power of standing, and fell on my back, carrying in my lips the mouth-piece separated from the cylinder, to the great alarm of Mr. Patrick Dwyer, who was noting the periods of inspiration.

Though experiments on successive inspirations of pure nitrous oxide might go far to determine whether or no any nitrogen, carbonic acid, and oxygen were products of respiration, yet I distinctly saw that it was impossible in this way to ascertain their quantities, supposing them produced, unless I could first determine the capacity of my lungs; and the different proportions of the gases remaining in the bronchial vessels after a complete expiration, when atmospheric air had been respired.

In some experiments (that I made on the respiration of hydrogen, with a view to determine whether carbonic acid was *produced* by the combination of carbon loosely combined in the venous blood, with the oxygen respired, or whether it was simply *given out* as excrementitious by this blood) I found, without however being able to solve the problem I had proposed to myself, that in the respiration of pure hydrogen, little or no alteration of volume took place; and that the residual gas was mingled with some nitrogen, and a little oxygen and carbonic acid.

From the comparison of these facts with those noticed in the last section and in Res. III. Div. I. there was every reason to suppose that hydrogen was not absorbed or altered when respired; but only mingled with the residual gases of the lungs. Hence, by making a full expiration of atmospheric air, and afterwards taking six or seven respirations of hydrogen in the mercurial

air-holder, and then making a complete expiration, I conjectured that the residual gas and the hydrogen would be so mingled, as that nearly the same proportions should remain in the bronchial vessels, as in the air-holder. By ascertaining these proportions, and calculating from them, I hoped to be able to ascertain with tolerable exactness, the capacity of my fauces and bronchia, as well as the composition of the gas remaining in them, after a complete expiration of common air.

IV. *Respiration of Hydrogen.*

The hydrogen that I employed, was procured from the decomposition of water by means of clean iron filings and diluted sulphuric and muriatic acids. It was breathed in the same manner as nitrous oxide, in the large mercurial air-holder.

After a complete voluntary exhaustion of my lungs in the usual posture, I found great difficulty in breathing hydrogen for so long as half a minute, so as to make a complete expiration of it. It produced uneasy feelings in the chest, momentary loss of muscular power, and sometimes a transient giddiness.

In some of the experiments that I made; on account of the giddiness, the results were rendered inconclusive, by my removing my mouth from the mouth-piece after expiration, before the assistant could turn the stop-cock.

The purity of the hydrogen was ascertained immediately before the experiment by the test of nitrous gas, and by detonation with oxygen or atmospheric air; generally 12 measures of atmospheric air were fired with 4 of the hydrogen, and if the diminution was to ten or a little more, the gas was judged to be pure.

After the experiment, when the complete expiration had been made and the common temperature restored; the volume of the gas was noticed, and then a small quantity of it thrown into the mercurial apparatus by means of the conducting tube, to be examined. The carbonic acid was separated from it by means of solution of potash or strontian; the quantity of oxygen it contained, was ascertained by means of nitrous gas of known composition; the superabundant nitrous gas was absorbed by solution of muriate of iron; and the proportions of hydrogen and nitrogen in the remaining gas, discovered by inflammation with atmospheric air or oxygen in the detonating tube by the electric spark.

a. The two following experiments made upon quantities of hydrogen, equal to those of the nitrous oxide respired in the experiments in the last section, are given as the most accurate of five.

E. 1. I respired, at 59°, 102 cubic inches of hydrogen apparently pure, for rather less than half a minute, making in this time seven quick respirations.

After the complete expiration, when the common temperature was restored, the gas occupied a space equal to 103 cubic inches nearly. These analyzed were found to consist of

Carbonic acid	.	.	.	.	4.0
Oxygen	.	.	.	.	3.7
Nitrogen	.	.	.	.	17.3
Hydrogen	.	.	.	.	78.0
					103.0

Now as in this experiment, the gas was increased in bulk only a cubic inch; supposing that after the complete expiration the gas in the lungs, bronchia and

fauces, was of nearly similar composition with that in the air-holder, and that no hydrogen had been absorbed by the blood, it would follow that 24 cubic inches of hydrogen remained in the internal organs of respiration, and consequently, by the rule of proportion, about 7·8 of the mixed residual gas of the common air. And then the whole quantity of residual gas of the lungs, supposing the temperature 59° , would have been 31·8 cubic inches; but as its temperature was nearly that of the internal parts of the body, 98° , it must have filled a greater space; calculating from the experiments of Guyton and Vernois,* about 37·5† cubic inches.

From the increase of volume, it would appear that a minute quantity of gas had been generated during the respiration, and this was, as we shall see hereafter, most probably carbonic acid.‡ Likewise there is reason to suppose, that a little of the residual oxygen must have been absorbed. Making allowances for those circumstances, it would follow, that the 37·5 cubic inches of gas remaining in my lungs, after a complete expiration of atmospheric air at animal heat 98° , equal to 31·8 cubic inches at 59° , were composed of

Nitrogen	.	.	.	.	.	21·9
Carbonic acid	.	.	.	.	.	4·9
Oxygen	.	.	.	.	.	5·0
						31·8

* *Annales de Chimie*, vol. i. page 279.

† This is only an imperfect approximation; the ratio of the increase of expansibility of gases to the increase of temperature, has not yet been ascertained. It is probable that the expansibility of gases is altered by their mixture. [Vide vol. ii. p. 233.]

‡ For there is reason to suppose the production of nitrogen.

E. 2. I respired for near half a minute in the mercurial air-holder at 61°, 182 cubic inches of hydrogen ; having made during this time, six long inspirations. After the last expiration, the gas filled a space nearly equal to 184 cubic inches, and analyzed, was found to consist of

Carbonic acid	.	.	.	.	4.8
Oxygen	.	.	.	.	4.6
Nitrogen	.	.	.	.	21.0
Hydrogen	.	.	.	.	153.6
					184.0

Now in this experiment, reasoning in the same manner as before, 28.4 cubic inches of hydrogen must have remained in the lungs, and likewise 5.5 of the atmospheric residual gas. Consequently, the whole residual gas was nearly equal to 34 cubic inches at 61°, which at 98° would become about 40.4 cubic inches. And reasoning as before, it would appear from this experiment, that the quantity of gas remaining in my lungs after a complete voluntary respiration, equalled at 98°, about 40 cubic inches, and at 61°, 34 nearly : making the necessary corrections ; that after common air had been breathed, these 34 cubic inches consisted of

Carbonic acid	.	.	.	.	4.1
Oxygen	.	.	.	.	5.5
Nitrogen	.	.	.	.	24.4

b. It would have been possible to prove the truth of the postulate on which the experiments were founded, by respiring common air or oxygen after the complete expiration of the hydrogen, for the same time as the hydrogen was respired, and in equal quantities.

For if portions of hydrogen were found in the air-holder equal to those of the residual gases in the two experiments, it would prove that a *uniform* mixture of residual gas with the gas inspired, was produced by the respiration. That this mixture must have taken place, appeared, however, so evident from analogous facts, that I judged the experimental proof unnecessary.

Indeed, as most gases, though of different specific gravities, when brought in contact with each other, assume some sort of union, it is more than probable, that gas inspired into the lungs, from being placed in contact with the residual gas on such an extensive surface, must instantly mingle with it. Hence, possibly one deep inspiration and complete expiration of the whole of a quantity of hydrogen, will be sufficient to determine the capacity of the lungs after complete voluntary exhaustion, and the nature of the residual air.

That two inspirations are sufficient, appears probable from the following experiment.

E. 3. After a complete voluntary expiration of common air, I made two deep inspirations of 141 cubic inches of hydrogen. After the complete expiration, they filled a space equal to rather more than 142 cubic inches, and analyzed, were found to consist of

Carbonic acid	3·1
Oxygen	4·5
Nitrogen	18·8
Hydrogen	115·6

142·0

Now calculating on the exhausted capacity of my lungs from this experiment, supposing uniform mixture, they would contain after expiration of common air, about

30·7 cubic inches at 58°, equal to 36 at 98°, composed of about

Nitrogen	20·9
Oxygen	5·8
Carbonic acid	4·0

30·7

One should suppose *à priori* that in this experiment much less of the residual oxygen of the lungs must have been absorbed, than in Experiments 1 and 2; yet there is no very marked difference in the portions evolved. That a tolerably accurate mixture took place, appears from the quantity of nitrogen. The smaller quantity of carbonic acid is an evidence in favour of its evolution from the venous blood.

c. It is reasonable to suppose that the pressure upon the residual gas of the exhausted lungs, must be nearly equal to that of the atmosphere. But as aqueous vapour is perpetually given out by the exhalents, and perhaps evolved from the moist coats of the pulmonary vessels, it is likely that the residual gas is not only fully saturated with moisture at 98°, but likewise impregnated with uncombined vapour; and hence its volume enlarged beyond the increment of expansion of temperature.

Considering all these circumstances, and calculating from the mean of the three experiments on the composition of the residual gas, I concluded,

1st. That the exhausted capacity of my lungs was equal to about 41 cubic inches.

2dly. That the gas contained in my bronchial vessels and fauces, after a complete expiration of atmospheric air, was equal to about 32 cubic inches, its temperature being reduced to 55°.

3dly. That these 32 cubic inches were composed of about

Nitrogen	23·0
Carbonic acid	4·1
Oxygen	4·9

d. In many experiments made in the mercurial air-holder on the capacity of my lungs under different circumstances, I found that I threw out of my lungs by a full forced expiration at temperatures from 58° to 62°,

	cub. in.	cub. in.
After a full voluntary inspiration, from	189	191
After a natural inspiration, from . .	78	79
After a natural expiration, from . .	67	68

So that making the corrections for temperature, it would appear, that my lungs in a state of voluntary inspiration, contained about 254 cubic inches; in a state of natural inspiration, about 135; in a state of natural expiration, about 118; and in a state of forced expiration 41.*

As the exhausted capacity as well as impleted capacity of the internal organs of respiration must be different in different individuals, according as the forms and size of their thorax, fauces, and bronchia are different, it would be almost useless to endeavour to ascertain a standard capacity. It is however probable, that a ratio exists between the quantities of air inspired in the natural and forced inspiration, those expired in the natural and forced expiration, and the whole capacity of the lungs. If this ratio were ascertained, a single experiment on the natural inspiration and expiration of common air, would enable us to ascertain

* This capacity is most probably below the medium; my chest is narrow, measuring in circumference but 29 inches, and my neck rather long and slender.

the quantity of residual gas in the lungs of any individual after a complete forced expiration.*

V. *Additional Observations and Experiments on the Respiration of Nitrous Oxide.*

a. Having thus ascertained the capacity of my lungs, and the composition of the residual gas of expiration, I proceeded to reason concerning the experiments in Section 3, on the respiration of nitrous oxide.

In *Exp.* 1, nearly 100 cubic inches of nitrous oxide, making the corrections on account of the common air, were respired for half a minute. In this time, they were reduced to 62 cubic inches, which consisted of 3·2 carbonic acid, 29 nitrous oxide, 4·1 oxygen, and 25·7 nitrogen.

But, as appears from the last section, there existed in the lungs before the inspiration of the nitrous oxide, about 32 cubic inches of gas, consisting of 23 nitrogen, 4·1 carbonic acid, and 4·9 oxygen, temperature being reduced to 59°. This gas must have been perfectly mingled with the nitrous oxide during the experiment; and consequently, the residual gas in the lungs after the experiment, was of the same composition as that in the air-holder.

Supposing it as before, to be about 32 cubic inches: from the rule of proportion they will be composed of

Nitrous oxide	14·7
Nitrogen	13·3
Carbonic acid	1·9
Oxygen	2·1

* Dr. Goodwyn, in his excellent work on the connexion of life with respiration, has detailed some experiments on the capacity of the lungs after natural expiration. He makes the medium capacity about 100 cubic inches, which agrees very well with my estimation.—page 27.

And the whole quantity of gas in the lungs and the air-holder, supposing the temperature 59° , will equal 94 cubic inches, which are composed of

Nitrous oxide	43.7
Nitrogen	39.0
Carbonic acid	5.2
Oxygen	6.1
	94.0

But before the experiment, the gas in the lungs and air-holder equalled 134 cubic inches, and these, reckoning for the common air, were composed of

Nitrous oxide	100
Nitrogen	24.3
Carbonic acid	4.1
Oxygen	5.6

Hence, it appears, that 56.3 cubic inches of nitrous oxide were absorbed in this experiment, and 13.7 of nitrogen produced, either by evolution from the blood, or decomposition of the nitrous oxide. The quantities of carbonic acid and oxygen approach so near to those existing after the respiration of hydrogen, that there is every reason to believe that no portion of them was produced in consequence of the absorption, or decomposition of the nitrous oxide.

b. In *Exp.* 2, calculating in the same manner, before the first inspiration, a quantity of gas equal to 216.5 cubic inches at 47° , existed in the lungs and air-holder, and these 216.5 cubic inches were composed of

Nitrous oxide	182.0
Nitrogen	24.9
Carbonic acid	4.1
Oxygen	5.5
	216.5

After the complete expiration, 160 cubic inches remained in the lungs and air-holder, which was composed of

Nitrous oxide	110.6
Nitrogen	36.3
Carbonic acid	6.8
Oxygen	6.3

Hence, it appears, that 71.4 cubic inches of nitrous oxide were absorbed in this experiment, and about 12 of nitrogen produced. The quantity of carbonic acid and oxygen is rather greater than that which existed in the experiments on hydrogen.

c. From these estimations, I learned that a small quantity of nitrogen was produced during the absorption of nitrous oxide in respiration. It remained to determine, whether this nitrogen owed its production to evolution from the blood, or to the decomposition of a portion of the nitrous oxide.

Analogical evidences were not in favour of the hypothesis of decomposition. It was difficult to suppose that a body requiring the temperature of ignition for its decomposition by the most inflammable bodies, should be partially absorbed and partially decomposed at 98°, by a fluid apparently possessed of uniform attractions.

It was more easy to believe, that from the immense quantity of nitrogen taken into the blood in nitrous oxide, the system soon became overcharged with this principle, which not being wholly expended in new combinations during living action, was liberated in the æriform state by the exhalents, or through the moist coats of the veins.

Now if the last rationale were true, it would follow, that the quantity of nitrogen produced in respiration,

ought to be increased in proportion as a greater quantity of nitrous oxide entered into combination with the blood.

d. To ascertain whether this was the case, I made, after full voluntary exhaustion of my lungs, one full voluntary inspiration and expiration of 108 cubic inches of nitrous oxide. After this, it filled a space nearly equal to 99 cubic inches. The quantities of carbonic acid and oxygen in these were not determined; but by the test of absorption by water, they appeared to contain only 18 nitrogen; which is very little more than should have been given from the residual gas of the lungs.

In a second experiment, I made two respirations of 108 cubic inches of nitrous oxide nearly pure. The diminution was to 95. On analysing these 95, I found, to my great surprise, that they contained only 17 nitrogen. Hence, I could not but suspect some source of error in the process.

I now introduced into a strong new silk bag, the sides of which were in perfect contact, about 8 quarts of nitrous oxide. From the mode of introduction, this nitrous oxide must have been mingled with a little common air, not however sufficient to disturb the results.

I then adapted a cork cemented to a long curved tube to my right nostril; the tube was made to communicate with the water apparatus; and the left nostril being accurately closed, and the mouth-piece of the silk bag tightly adapted to the lips, I made a full expiration of the common air of my lungs, inspired nitrous oxide from the bag, and by carefully closing the mouth-piece with my tongue, expired it through the curved tube into the water apparatus. In this way, I made

nine respirations of nitrous oxide. The expired gas of the first respiration was not preserved; but part of the gas of the second, third, fifth, seventh and ninth, were caught in separate graduated cylinders. The second, analyzed by absorption, consisted of about 29 absorbable gas, which must have been chiefly nitrous oxide; and 17 unabsorbable gas, which must have been chiefly nitrogen; and the third of 22 absorbable gas, and 8 unabsorbable. The fifth was composed of 27 to 6; the seventh of 23 to 7, and the ninth of 26 to 11.

e. Though the results of these experiments were not so conclusive as could be wished; yet, comparing them with those of the experiments in section 3, it seemed reasonable to conclude, that the production of nitrogen was increased, in proportion as the blood became more fully impregnated with nitrous oxide.

From this conclusion, compared with the phenomenon noticed in section 2, and in Div. I. section 4, I am induced to believe that the production of nitrogen during the respiration of nitrous oxide, is not owing to the decomposition of part of the nitrous oxide, in the aëriform state *immediately* by the attraction of the red particles of venous blood for its oxygen; but that it is rather owing to a new arrangement produced in the principles of the impregnated blood, during circulation; from which, becoming supersaturated with nitrogen, it gives it out through the moist coats of the vessels.

For if any portion of nitrous oxide were decomposed immediately by the red particles of the blood, one should conjecture, that the quantity of nitrogen produced, ought to be greater during the first inspirations, before these particles became fully combined with condensed oxygen. If, on the contrary, the whole of the

nitrogen and oxygen of the nitrous oxide were both combined with the blood, and carried through the pulmonary veins and left chamber of the heart to the arteries; then, supposing the oxygen chiefly expended in living action, whilst the nitrogen was only partially consumed in new combinations, it would follow, that the venous blood of animals made to breathe nitrous oxide, hypersaturated with nitrogen, must be different from common venous blood; and this we have reason to believe from the phenomena in Div. I. section 4, is actually the case.

f. Besides the nitrogen generated, during the respiration of nitrous oxide, we have noticed the evolution of other products, carbonic acid,* and water.

Now as nearly equal quantities of carbonic acid are produced, whether hydrogen or nitrous oxide is respired, provided the process is carried on for the same time; there is every reason to believe, as we have said before, that no part of the carbonic acid produced, is generated from the immediate decomposition of nitrous oxide by carbon existing in the blood.

Consequently, in these experiments, it must be either evolved from the venous blood; or formed by the slow combination of the oxygen of the residual air of respiration with the charcoal of the blood.

But if it was produced by the decomposition of residual atmospheric air, it would follow, that its volume must be much less than that of the oxygen of the residual air which had disappeared; for some of this oxygen must have been *absorbed* by the blood, and during the conversion of oxygen into carbonic acid by charcoal, a slight diminution of volume is produced.†

* The oxygen, as we have before noticed, most probably wholly existed in the residual gas.

† [According to his later researches, the solution of carbon in oxygen

In the experiments when nitrous oxide and hydrogen were respired for about half a minute, the medium quantity of carbonic acid produced, was 5.6 cubic inches nearly.

Now we will assume, that the quantity of carbonic acid produced, is in the ratio of the oxygen diminished; and there is every reason to believe, that in the expiration of atmospheric air, the expired air and the residual air are nearly of the same composition.

Hence, no more carbonic acid can remain in the lungs or be produced from the residual gas after the complete expiration of common air, than that which can be generated from a volume of atmospheric air equal to the residual gas of the lungs.

The residual gas of the lungs, after complete expiration, equals at 55°, 32 cubic inches, and 32 cubic inches of common air contain 8.6 cubic inches of oxygen.

But in the experiments on the respiration of hydrogen, not only 5.6 cubic inches of carbonic acid were produced, but more than 4 of residual oxygen remained unabsorbed.

Hence it appears impossible that all the carbonic acid evolved from the lungs during the respiration of nitrous oxide or hydrogen could have been produced by the combination of charcoal in the venous blood with residual atmospheric oxygen: there is consequently every reason to believe that it is wholly or partially liberated from the venous blood through the moist coats of the vessels.

g. The water carried out of the lungs in solution by the expired gas of nitrous oxide, could neither have been wholly or partially formed by the decomposition of

gas is without change of volume. Vide Elements of Chemical Philosophy, article Carbon.]

nitrous oxide. The coats of the vessels in the lungs, and indeed in the whole internal surface of the body, are always covered with moisture, and the solution of part of this moisture by the inspired heated gas, and its deposition by the expired gas, are sufficient causes for the appearance of the phenomenon.

There are no reasons for supposing that any of the residual atmospheric oxygen is immediately combined with fixed or nascent hydrogen, or hydrocarbonate, in the venous blood at 98° , by slow combustion, and consequently none for supposing that water is immediately formed in respiration.

The evolution of water from the vessels in the lungs, is almost certain from numerous analogies.

h. As from the experiments in section 2, it appeared that nitrous oxide was capable of being combined with oxygenated blood, and vice versa, blood impregnated with nitrous oxide capable of oxygenation; I was curious to ascertain what changes would be effected in nitrous oxide when it was respired, mingled with atmospheric air or oxygen. For this purpose, without making a very delicate experiment, I breathed in the large mercurial air-holder about 112 cubic inches of nitrous oxide, mingled with 44 of common air, for near half a minute, in the usual mode. The gas, after expiration, filled a space nearly equal to 119. I did not exactly ascertain the composition of the residual gas; it supported flame rather better than common air, and after the nitrous oxide was absorbed, gave much less diminution with nitrous gas than atmospheric air.

i. I breathed a mixture of four quarts of nitrous oxide with three quarts of hydrogen, in a dry silk bag, for near a minute; an evident diminution was produced; but on account of the mode of experimenting it was

impossible to determine the quantity of nitrous oxide absorbed, or the exact nature of the products. When a taper was introduced into a little of the residual gas, it inflamed with a very feeble explosion. Now a mixture of 4 parts nitrous oxide and 3 hydrogen, detonates when inflamed with very great violence.

k. Nitrous oxide can be respired without danger by the human animal for a much longer time than that required for the death of the smaller quadrupeds in it.

I have breathed it two or three times in a considerable state of purity, in a dry silk bag, for four minutes and a quarter, and four minutes and a half: some diseased individuals have respired it for upwards of five minutes.

In the infancy of my experiments, from general appearances, I thought that the proportion of nitrous oxide absorbed in respiration was greater in the first inspirations than the last; but this I have since found to be a mistake. In the last respirations the apparent absorption is indeed less; but this is on account of the increased evolution of nitrogen from the blood. When nitrous oxide is respired for a long time, the last inspirations are always fuller and quicker than the first; but the consumption by the same individual is nearly in the ratio of the time of respiration. Three quarts, *i. e.* about 174 cubic inches, are consumed so as to be unfit for respiration, by a healthy individual with lungs of moderate capacity, in about a minute and quarter; six quarts, or 348 cubic inches, last generally for two minutes and a half, or two minutes and three quarters; eight quarts, or 464 cubic inches, for more than three minutes and half; and twelve, or 696 cubic inches, for nearly five.

The quantities of nitrous oxide absorbed by the same individual, will, as there is every reason to suppose, be different under different circumstances, and will proba-

bly be governed in some measure by the state of the health. It is reasonable to suppose, that the velocity of the circulation must have a considerable influence on the absorption of nitrous oxide; probably in proportion as it is greater, a larger quantity of gas will be consumed in equal times.

I am inclined, from two or three experiments, to believe that nitrous oxide is absorbed more rapidly after hearty meals, or during stimulation from wine or spirits, than at other times. As its absorption appears to depend on a simple solution in the venous blood, probably diminution of temperature will increase its capability of being absorbed.

l. The quantities of nitrous oxide absorbed by different individuals, will probably be governed in some measure by the size of their lungs and the surface of the blood vessels, all other circumstances being the same.

From the observations that I have been able to make on the absorption of nitrous oxide, as compared with the capacity of the lungs, the range of the consumption of different individuals does not extend to more than a pint, or 30 cubic inches at the maximum dose.

We may therefore conclude, that the medium consumption of nitrous oxide by the respiration of different individuals, is not far from two cubic inches, or about a grain every second, or 120 cubic inches, or 60 grains every minute.

m. When nitrous oxide is breathed in tight silk bags, towards the end of the experiment, as the internal surface becomes moist, as I have before mentioned, a certain quantity of common air penetrates through it and becomes mixed with the residual gas of the experiment; but this quantity is always too small to destroy any of the effects of the nitrous oxide. The residual gas of

the common air, the nitrogen and carbonic acid produced in the process, and the residuum of the admitted atmospheric air, hardly ever amount after the experiment, to one-half of the volume of the nitrous oxide absorbed. There is consequently, a perfect propriety in successively inspiring and expiring the whole of a given quantity of nitrous oxide, till it is nearly consumed. In the respiration of nitrous oxide, as the gas is absorbed and not decomposed, little will be gained in effect, by perpetually inspiring and expiring new portions, whilst an immense quantity of gas will be idly wasted, and this circumstance, considering the expense of the substance, is of importance.

VI. *On the Respiration of Atmospheric Air.*

Having thus ascertained the absorption of nitrous oxide in respiration, and the evolution of nitrogen and carbonic acid from the lungs during its absorption: considering atmospheric air as a compound in which principles identical with those in nitrous oxide existed, though in different quantities and looser combination, I was anxious to compare the changes effected in this gas by respiration, with those produced in nitrous oxide and oxygen; particularly as they are connected with the health and life of animals.

The ingenious experiments of Lavoisier and Goodwyn, prove the consumption of oxygen in respiration, and the production of carbonic acid. From many experiments on the respiration of common air, Dr. Priestley suspected that a certain portion of nitrogen, as well as oxygen, was absorbed by the venous blood.

b. In the following experiments on the respiration of atmospheric air in the mercurial air-holder; the com-

position of the gas before inspiration and after expiration, was ascertained in the following manner.

40 measures of it were agitated over mercury in solution of caustic potash, and suffered to remain in contact with it for two or three hours. The diminution was noted, and the gas absorbed judged to be carbonic acid. Twenty measures of the gas, freed from carbonic acid, were mingled with 30 of nitrous gas, in a tube of .5 inch diameter; they were not agitated,* but suffered to rest for an hour, or an hour and half, when the volume occupied by them was noticed: and $50-m$, the volume occupied, divided by 3 considered as the oxygen x , and $20-x$ considered as the nitrogen.

c. To ascertain the changes effected in atmospheric air by single inspirations,

I made, after a complete voluntary exhaustion of my lungs, at temperature 61° , one inspiration and expiration of 141 cubic inches of atmospheric air. After expiration, they filled a space equal to 139 cubic inches nearly. These 139 cubic inches analyzed were found to consist of

	cub. in.
Nitrogen	101
Oxygen	32
Carbonic acid	6

The 141 cubic inches before inspiration, were composed of 103 nitrogen, 1 carbonic acid, and 37 oxygen. The time taken to perform the inspiration and full expiration, was nearly a quarter of a minute.

I repeated this experiment seven or eight times, and

* When they are agitated, a greater proportion of nitrous gas is absorbed, condensed in the nitric acid by the water; and to find the

$$\text{oxygen, } x = \frac{50-m}{3.4} \text{ or } \frac{50-m}{3.5}$$

the quantity of oxygen absorbed was generally from 5 to 6 cubic inches, the carbonic acid formed from 5 to 5.5, and the quantity of nitrogen apparently diminished by from 1 to 3 cubic inches.

Ex. 2. I made, after a voluntary expiration of common air, one inspiration and full expiration of 100 cubic inches of atmospheric air. It was diminished nearly to $98\frac{3}{4}$ or 99 cubic inches, and analyzed was found to consist of

	cub. in.
Nitrogen	71.7
Oxygen	22.5
Carbonic acid	4.5

This experiment I likewise repeated four or five times, with very little difference of result, and there always seemed to be a small diminution of nitrogen. I made no corrections on account of the residual air of the lungs in these processes, because there was every reason to suppose that it was always of similar composition.

c. Before I could ascertain whether similar changes were effected in atmospheric air, by natural inspirations as by forced ones, I was obliged to practise respiration in the mercurial air-holder, by suffering the conducting tube to communicate with the atmosphere till I had attained the power of breathing in it naturally, without labour or attention; I then found by a number of experiments, that I took into my lungs at every natural inspiration, about 13 cubic inches of air, and that I threw out of my lungs at every expiration,* rather less than this quantity; about $12\frac{3}{4}$ cubic inches.

The mean composition of the 13 cubic inches of air inspired, was

* The diminution of air by single inspirations, was particularly noticed by Dr. Goodwyn.

	cub. in.
Nitrogen	9.5
Oxygen	3.4
Carbonic acid	0.1
That of the 12.7 of air expired	
Nitrogen	9.3
Oxygen	2.2
Carbonic acid	1.2

These results I gained from more than 20 experiments, so that I could not possibly entertain any doubt of this accuracy.

I found, by making a person observe my respirations when I was inattentive to the process, that I made about 26 or 27 natural inspirations in a minute. So that calculating from the above estimations, it would follow, that 31.6 cubic inches of oxygen were consumed, 5.2 inches of nitrogen lost in respiration every minute, whilst 26.6 cubic inches of carbonic acid were produced.

To collect the products of a great number of natural expirations so as to ascertain whether their composition corresponded with the above accounts, I proceeded in the following manner:

I fastened my lips tight on the mouth-piece of the exhausted air-holder, and suffering my nostrils to remain open, inspired naturally through them, throwing the expired air through my mouth into the air-holder.

In many experiments, I found that in about half a minute, I made in this way 14 or 15 expirations. The mean quantity of air collected was 171 cubic inches, and consisted of

	cub. in.
Nitrogen	128
Oxygen	29
Carbonic acid	14

Comparing these results with the former ones, we find the mean quantities of air respired in equal terms rather less; but the proportions of carbonic acid, nitrogen and oxygen in the respired air, nearly identical.

e. To ascertain the changes effected in a given quantity of atmospheric air by continued respirations, I breathed after a complete expiration, at temperature 63° , 161 cubic inches of air for near a minute, making in this time, 19 deep inspirations. After the complete expiration, which was very carefully made, the gas filled a space nearly equal to 152 cubic inches, so that 9 cubic inches of gas had disappeared,

The 152 cubic inches analyzed were found to consist of

	cub. in.
Nitrogen	111.6
Oxygen	23.
Carbonic acid	17.4

The 161 cubic inches before inspiration were composed of

	cub. in.
Nitrogen	117.0
Oxygen	42.4
Carbonic acid	1.6

But the residual gas in the lungs before the experiment was of different composition from that remaining in the lungs after the experiment. Making corrections on account of this circumstance, as in section 4, it appears that about 5.1 of nitrogen were absorbed in respiration, 23.9 of oxygen consumed, and 12 of carbonic acid produced.

I repeated this experiment three times; in each experiment the diminution after respiration was nearly

the same ; and the residual gas, making the necessary allowances, of similar composition. So that supposing the existence of no source of error in the experiments from which the quantity and composition of the residual gas of the lungs were estimated in section 4, the absorption of nitrogen by the venous blood, appears almost demonstrated.

f. To compare the changes effected in atmospheric air by respiration of the smaller quadrupeds, with those in the experiments just detailed, I introduced into a jar of the capacity of 20 inches filled with mercury in the mercurial trough, 15 cubic inches of atmospheric air which had been deprived of its carbonic acid by long exposure, to solution of potash.

Temperature being 64° , a healthy small mouse was quickly passed under the mercury into the jar, and suffered to rest on a very thin bit of cheese, which was admitted immediately after.

He continued for near 40 minutes without apparently suffering, occasionally raising himself on his hind legs. At the end of 50 minutes, he was lying on his side, and in 55 minutes was apparently dying. He was now carefully taken out through the mercury by the tail, and exposed before the fire, where he soon recovered. After the cheese had been carefully removed, the gas in the jar filled a space nearly equal to 14 cubic inches; so that a diminution of a cubic inch had taken place. These 14 cubic inches analyzed, were found to consist of

	cub. in.
Carbonic acid	2.0
Oxygen	1.0
Nitrogen	10.6

The 15 cubic inches before the experiment, consisted of

	cub. in.
Oxygen	4
Nitrogen	11

Hence it appeared, that 2·6 cubic inches of oxygen had been consumed, 2 cubic inches of carbonic acid produced, and about 0·4 of nitrogen lost.

The relation between the quantities of oxygen consumed in this experiment, and the carbonic acid produced, are nearly the same as that of those in the experiments just detailed; but the quantity of nitrogen lost is much smaller.

VII. *Respiration of Oxygen.*

The gases before and after respiration were analyzed in these experiments in the manner described in the last section, except that 3 of nitrous gas were always employed to 1 of oxygen.

Ex. 1. At temperature 53°, after a full forced respiration, I respired in the mercurial air-holder, for half a minute, 102 cubic inches of oxygen, making seven very long and deep inspirations. After the complete expiration, the gases filled a space equal to 93 cubic inches; these 93 cubic inches analyzed were found to consist of

	cub. in.
Carbonic acid	5·9
Nitrogen	33·8
Oxygen	53·3

The 102 cubic inches before the experiment, were composed of

	cub. in.
Oxygen	78
Nitrogen	24

The residual gas in the lungs before the experiment,

was 32 cubic inches, and composed of about 23 nitrogen, 4·1 carbonic acid, and 4·9 oxygen, section 4. The residual gas after expiration, was composed of 18·2 oxygen, 2 carbonic acid, and 11·8 nitrogen.

Hence the whole of the gas in the lungs and air-holder before inspiration, was 134 cubic inches, composed of

Oxygen	82·9
Nitrogen	47·0
Carbonic acid	4·1

And after respiration, 125 cubic inches, consisting of

Oxygen	71·5
Nitrogen	45·6
Carbonic acid	7·9

So that comparing the quantities, it appears, that 11·4 of oxygen and 1·4 of nitrogen, were consumed in this experiment, and 3·8 of carbonic acid produced.

I was much surprised at the small quantity of oxygen that had been consumed in this experiment. This quantity was less than that expended during the respiration of atmospheric air for half a minute: the portion of carbonic acid evolved was likewise smaller. I could detect no source of inaccuracy, and it was difficult to suppose that the greater depth and fulness of the inspirations could make any difference.

Ex. 2. I now respired at the same temperature, after a full expiration, 162 cubic inches of gas, composed of 133 oxygen and 29 nitrogen for two minutes, imitating as much as possible the natural respiration. After the experiment, they filled a space equal to 123 cubic inches. And when the analysis and calculations had been made as in the last experiment, it appeared that 57 cubic inches of oxygen, and 2 of nitrogen had been absorbed, whilst 21 cubic inches of carbonic acid had been formed.

Now from the estimations in the last section, it appears that 63 cubic inches of oxygen are consumed, and about 52 cubic inches of carbonic acid produced every two minutes during the natural respiration of common air. So that supposing the experiment accurate, 6 cubic inches of oxygen less are absorbed, and 30 cubic inches less of carbonic acid produced every minute, when oxygen nearly pure is respired, than when atmospheric air is respired.

Both these experiments were made in the morning, at a time when I was in perfect health; so that there could be apparently no source of error from accidental circumstances.

The uncommon and unexpected nature of the results, made me, however, very sceptical concerning them; and before I would draw any inferences, I resolved to ascertain the comparative consumption of atmospheric air and oxygen by the smaller quadrupeds, for which purpose, I made the following experiment.

Ex. 3. Of two strong and healthy small mice, apparently of the same breed, and exactly similar,

One was introduced into a jar containing 10 cubic inches and a half of oxygen, and 3 cubic inches of nitrogen, and made to rest on a bit of cheese.

The other was introduced into a jar containing fifteen cubic inches and a half of atmospheric air, and made to rest in the same manner on cheese.

The mouse in oxygen began apparently to suffer in about half an hour, and occasionally panted very much; in about an hour he lay down on his side as if dying. The jars were often agitated, that the gases might be well mingled.

The mouse in atmospheric air became very feeble in 40 minutes, and at the end of 50 minutes was

taken out through the mercury alive, but unable to stand.

The mouse in oxygen was taken out in the same manner after an hour and quarter, alive, but motionless, and breathing very deeply.

The gas in the jars was examined. That in the oxygen jar filled a space exactly equal to 12·7 cubic inches, and analyzed was found to consist of 1·7 carbonic acid, 2·6 of nitrogen, and 8·4 of oxygen. So that absolutely, 2·1 cubic inches of oxygen and ·4 of nitrogen had been consumed, and 1·7 of carbonic acid produced.

The gas in the atmospheric air jar was diminished nearly to 14·4, and consisted of 2·1 carbonic acid, 1·4 oxygen; and 10·9 nitrogen. So that 2·7 of oxygen and ·5 of nitrogen, had been consumed by the mouse; and 2·1 of carbonic acid produced.

Hence it appears, that the mouse in atmospheric air consumed nearly one-third more oxygen and produced nearly one-fourth more carbonic acid in respiration in 55 minutes, than the other in an hour and quarter in oxygen. And if we consider the perpetual diminution of the oxygen of the atmospheric air; from which at last it became almost incapable of supporting the life of the animal; we may conclude, that the quantity of oxygen consumed by it, had the air been perpetually renovated, would have been much more considerable.

I design, very shortly, to repeat these experiments, and to make others on the comparative consumption of oxygen and atmospheric air, by the larger quadrupeds. Whatever may be the results, I hope to be able to ascertain from them, why pure oxygen is incapable of supporting life.*

* [This very important question still remains to be answered. The

VIII. *Observations on the Changes effected in the Blood, by Atmospheric Air and Oxygen.*

From the experiments of Mr. Cigna and Dr. Priestley,* it appears that the coagulum of the venous blood becomes florid at its surface when exposed to the atmosphere, though covered and defended from the immediate contact of air by a very thick stratum of serum.

Hence it is evident, that serum is capable of dissolving either the whole compound atmospheric air, or the oxygen of it.†

Supposing, what indeed is most probable from numerous analogies, that it dissolves the whole compound, it would follow, that the colouring of the coagulum of blood under serum depended upon the decomposition of the atmospheric air condensed in the serum, the oxygen‡ of it combining with the red particles, and the blood of animals which die in oxygen gas, equally in the veins and arteries, in the right and left cavities of the heart is of a bright florid hue. Death appears to be connected with cessation of respiration and of the heart's action; the former perhaps first, and the latter as a consequence.]

* Dr. Priestley found that it likewise became florid at the surface when covered by milk; but that it underwent little or no alteration of colour under water and most other fluids, vol. iii. p. 372.

† [According to the experiments of Berzelius, and also some which I have made, serum has little or no power of absorbing either oxygen or atmospheric air.]

‡ There are many analogous decompositions. Dr. Priestley noticed (and I have often made the observation) that green oxide of iron, or the precipitate from pale green sulphate of iron by caustic alkali, became red at the surface, when covered by a thick stratum of water. In my experiments on the green muriate and sulphate of iron, I observed that part of some dark oxide of iron which was at the bottom of a trough of water 9 inches deep, became red at the surface nearly in the same time as another portion of the same precipitation that was exposed to the atmosphere. This oxygenation must depend upon the decomposition of atmospheric air constantly dissolved by the water.

nitrogen either remaining dissolved in the fluid, or being liberated through it into the atmosphere.

Now the circulating blood consists of red particles, floating in and diffused through serum and coagulable lymph.

In natural respiration, the red particles are rendered of a brighter tinge during the passage of the blood through the pulmonary veins. And as we have seen in the last sections, during respiration atmospheric air is decomposed, all the oxygen of it consumed, *apparently* a small portion of the nitrogen lost, and a considerable quantity of carbonic acid produced.

It seems therefore reasonable to suppose, that the whole compound atmospheric air passing through the moist coats of the vessels is first dissolved by the serum of the venous blood, and in its condensed state, decomposed by the affinity of the red particles for its oxygen; the greater part of the nitrogen being liberated unaltered; but a minute portion of it possibly remaining condensed in the serum and coagulable lymph, and passing with them into the left chamber of the heart.

From the experiments on the respiration of nitrous oxide and hydrogen, it appears that a certain portion of the carbonic acid produced in respiration, is evolved from the venous blood; but as a much greater quantity is generated during the respiration of common air and oxygen, than during that of hydrogen in equal times, it is not impossible but that some portion of it may be formed by the combination of charcoal in the red particles with the oxygen dissolved in the serum; but this can only be determined by farther experiments.

Supposing that no part of the water evolved in solution by the expired gas of common air is formed immediately in respiration, it will follow that a very consi-

derable quantity of oxygen must be constantly *combined* with the red particles, even allowing the consumption of a certain portion of it to form carbonic acid; for the carbonic acid evolved, rarely amounts to more than three-fourths of the volume of the oxygen consumed.

Perhaps the serum of the blood is capable of dissolving a larger quantity of atmospheric air than of pure oxygen. On this supposition, it would be easy to explain the smaller consumption of oxygen in the experiments in the last section.*

* [The above hypothesis does not differ very materially from that which the author brought forward in his last work, "The Consolations in Travel."

It is curious to observe how opinion has fluctuated relative to the effects of respiration, both on the air and on the blood, and how, during the last forty years, there have been on the subject almost as many hypotheses as inquirers; and how physiologists now seem to be retracing their steps, and returning to the doctrines advanced at the beginning of this period, especially relative to the absorption of oxygen and azote in the lungs, and the evolution in smaller proportion of carbonic acid. Dr. Edwards' researches are strongly in favour of these views; and from very many experiments which I made some years ago, I am much disposed to adopt them. I shall extract from notes kept of my experiments a few of the results, chiefly relating to the absorption of oxygen.

A half-grown rabbit was placed in a glass jar containing 232 cubic inches of atmospheric air;—the jar was inverted in water, after its mouth had been covered with wet bladder, which was tied firmly. The animal died in an hour and four minutes. The bladder was rather less tense than at the commencement of the experiment. The air examined by means of lime-water and phosphorus was found to consist of

13·13 Carbonic acid gas.

4·04 Oxygen.

82·83 Azote.

As much air as possible was collected from the mouth, nose, and fauces; it did not exceed $\frac{1}{20}$ of a cubic inch. A ligature was then applied to the upper parts of the trachea, and the chest was opened;—the lungs were very much collapsed; they were punctured and forcibly pressed; only about $\frac{1}{100}$ of a cubic inch of air was collected, and about the same quantity was obtained on opening the trachea,—carbonic acid and oxy-

IX. *Observations on the Respiration of Nitrous Oxide.*

The experiments in the First Division of this Research, prove that nitrous oxide when respired by ani-

gen were detected in it, but the quantity was too small to admit of accurate analysis. The stomach was full of food; and the intestines were free from air, excepting the colon, which contained about a cubic inch, and this was found to consist of

28 Carbonic acid.

3 Oxygen.

79 Azote.

It should be mentioned that urine was voided equal in volume to about $\frac{1}{2}$ cubic inch; which at farthest, it is probable, could only have absorbed its own bulk of carbonic acid gas.

In another experiment a ligature was passed under the trachea of a rabbit, and it was suddenly tied. The animal died in about three minutes. The chest was immediately opened under water: the lungs were partially collapsed; the edges of them were semitransparent, and their cells were distended with air. A small portion of the edge of the middle lobe of the left lung was snipped off with a scissors;—the whole of the air of the lung passed out at this opening, and very little pressure was required to expel it completely; it was collected, and amounted to $\frac{1}{4}$ cubic inch. It consisted of

2 Carbonic acid.

6 Oxygen.

92 Azote.

For comparison, another experiment was made. A rabbit, of the same age and size as the preceding, was immersed in water of temperature 70°, all but its head; and when a small receiver was got in readiness, the head was immersed also. Three or four bubbles of air which appeared to come from the mouth were lost; in two or three seconds $\frac{7}{16}$ cubic inch of air were expired, and collected, and a few bubbles more were given out by the animal in the convulsion of dying. The chest was immediately opened under water, the trachea having been previously tied; the lungs were punctured and pressed; from neither of them could any appreciable quantity of air be obtained. The air expired was found to consist of

4.2 Carbonic acid gas.

7.0 Oxygen.

78.8 Azote.

mals, produces peculiar changes in their blood and in their organs, first connected with increased living action; but terminating in death.

From the experiments in this Division, it appears that nitrous oxide is rapidly absorbed by the circulating venous blood, and of course its condensed oxygen and nitrogen distributed in the blood over the whole of the system.

Concerning the changes effected in the principles of the impregnated blood during circulation and its action upon the nervous and muscular fibre, it is useless to reason in the present state of our knowledge.

It would be easy to form theories referring the action of blood impregnated with nitrous oxide, to its power of supplying the nervous and muscular fibre with such proportions of condensed nitrogen, oxygen and light or ethereal fluid, as enabled them more rapidly to pass through those changes which constitute their life; but

The results of these three experiments, in relation to the point, for the illustration of which they were brought forward, require very little comment. From the first, it would appear, that there was an absorption of oxygen,—but trifling in comparison with the second;—and that in the second, there was an absorption not only of oxygen, but also of carbonic acid gas.

I find it noted as worthy of remark, that in the first and third experiments the lungs were in a similar state,—that almost all the air was expelled from them by the violent expiration preceding death,—and that they resembled almost the foetal lungs. I would refer to these observations some intelligent critics, who have asserted that the estimate of capacity of the author's own lungs at 41 cubic inches after a forced expiration, was very much under-rated. These inquirers do not appear to have taken into account in their calculation the great power of the diaphragm in compressing and emptying the lungs;—a power so great, that supposing the lungs perfectly healthy, and the diaphragm acting energetically, there seems to be no reason *à priori* against its forcing out all the air, with the assistance of the other muscles, and reducing the lungs actually to their void foetal state.]

such theories would be only collections of terms derived from known phenomena, and applied by loose analogies of language to unknown things.

We are unacquainted with the composition of dead organized matter ; and new instruments of experiment and new modes of research must be found, before we can ascertain even our capabilities of discovering the laws of life.

RESEARCH IV.

RELATING TO THE EFFECTS PRODUCED BY THE RESPIRATION OF NITROUS OXIDE UPON DIFFERENT INDIVIDUALS.

DIVISION I.

HISTORY OF THE DISCOVERY.—EFFECTS PRODUCED BY THE RESPIRATION OF DIFFERENT GASES.

A SHORT time after I began the study of Chemistry, in March 1798, my attention was directed to the dephlogisticated nitrous gas of Priestley, by Dr. Mitchill's Theory of Contagion.*

The fallacy of this theory was soon demonstrated, by a few coarse experiments made on small quantities of the gas procured from zinc and diluted nitrous acid. Wounds were exposed to its action, the bodies of animals were immersed in it without injury; and I breathed it mingled in small quantities with common air, without remarkable effects. An inability to procure it in sufficient quantities, prevented me at this time from pursuing the experiments to any greater extent. I communicated an account of them to Dr. Beddoes.

* Dr. Mitchill attempted to prove from some phenomenon connected with contagious diseases, that dephlogisticated nitrous gas which he called oxide of septon, was the principle of contagion, and capable of producing the most terrible effects when respired by animals in the minutest quantities, or even when applied to the skin or muscular fibre.

In 1799, my situation in the Medical Pneumatic Institution, made it my duty to investigate the physiological effects of the aëriform fluids, the properties of which presented a chance of useful agency. At this period I recommenced the investigation.

A considerable time elapsed before I was able to procure the gas in a state of purity, and my first experiments were made on the mixtures of nitrous oxide, nitrogen and nitrous gas, which are produced during metallic solutions.

In the beginning of March, I prepared a large quantity of impure nitrous oxide from the nitrous solution of zinc. Of this I often breathed the quantities of a quart and two quarts generally mingled with more than equal parts of oxygen or common air. In the most decisive of those trials, its effects appeared to be depressing, and I imagined that it produced a tendency to fainting: the pulse was certainly rendered slower under its operation.

At this time, Mr. Southey respired it in an highly diluted state; it occasioned a slight degree of giddiness, and considerably diminished the quickness of his pulse.

Mr. C. Coates likewise respired it highly diluted, with similar effects.

In April, I obtained nitrous oxide in a state of purity, and ascertained many of its chemical properties. Reflections upon these properties and upon the former trials, made me resolve to endeavour to inspire it in its pure form, for I saw no other way in which its respirability or powers could be determined.*

* I did not attempt to experiment upon animals, because they die nearly in equal times in non-respirable gases, and gases incapable of supporting life and possessed of no action on the venous blood.

I was aware of the danger of this experiment. It certainly would never have been made if the hypothesis of Dr. Mitchill had in the least influenced my mind. I thought that the effects might be possibly depressing and painful, but there were many reasons which induced me to believe that a single inspiration of a gas apparently possessing no immediate action on the irritable fibre, could neither destroy nor immediately injure the powers of life.

On April 11th, I made the first inspiration of pure nitrous oxide; it passed into the bronchia without stimulating the glottis, and produced no uneasy feeling in the lungs.

The result of this experiment proved that the gas was respirable, and induced me to believe that a farther trial of its effects might be made without danger.

On April 16th, Dr. Kinglake being accidentally present, I breathed three quarts of nitrous oxide from and into a silk bag for more than half a minute, without previously closing my nose or exhausting my lungs.

The first inspirations occasioned a slight degree of giddiness. This was succeeded by an uncommon sense of fulness of the head, accompanied with loss of distinct sensation and voluntary power, a feeling analogous to that produced in the first stage of intoxication; but unattended by pleasurable sensation. Dr. Kinglake, who felt my pulse, informed me that it was rendered quicker and fuller.

This trial did not satisfy me with regard to its powers; comparing it with the former ones I was unable to determine whether the operation was stimulant or depressing.

I communicated the result to Dr. Beddoes; and on

April the 17th, he was present, when the following experiment was made.

Having previously closed my nostrils and exhausted my lungs, I breathed four quarts of nitrous oxide from and into a silk bag. The first feelings were similar to those produced in the last experiment; but in less than half a minute, the respiration being continued, they diminished gradually, and were succeeded by a sensation analogous to gentle pressure on all the muscles, attended by a highly pleasurable thrilling, particularly in the chest and the extremities. The objects around me became dazzling and my hearing more acute. Towards the last inspirations, the thrilling increased, the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in; I recollect but indistinctly what followed; I know that my motions were various and violent.

These effects very soon ceased after respiration. In ten minutes, I had recovered my natural state of mind. The thrilling in the extremities, continued longer than the other sensations.*

This experiment was made in the morning; no languor or exhaustion was consequent, my feelings throughout the day were as usual, and I passed the night in undisturbed repose.

The next morning the recollections of the effects of the gas were very indistinct, and had not remarks written immediately after the experiment recalled them to my mind, I should have even doubted of their reality. I was willing indeed to attribute some of the strong emotion to the enthusiasm, which I supposed must have

* Dr. Beddoes has given some account of this experiment, in his "Notice of some Observations made at the Medical Pneumatic Institution." It was noticed in Mr. Nicholson's Phil. Journal for May 1799.

been necessarily connected with the perception of agreeable feelings, when I was prepared to experience painful sensations. Two experiments, however, made in the course of this day, with scepticism, convinced me that the effects were solely owing to the specific operation of the gas.

In each of them I breathed five quarts of nitrous oxide for rather a longer time than before. The sensations produced were similar, perhaps not quite so pleasurable; the muscular motions were much less violent.

Having thus ascertained the powers of the gas, I made many experiments to ascertain the length of time for which it might be breathed with safety, its effects on the pulse, and its general effects on the health when often respired.

I found that I could breathe nine quarts of nitrous oxide for three minutes, and twelve quarts for rather more than four. I could never breathe it in any quantity, so long as five minutes. Whenever its operation was carried to the highest extent, the pleasurable thrilling at its height about the middle of the experiment, gradually diminished; the sense of pressure on the muscles was lost; impressions ceased to be perceived; vivid ideas passed rapidly through the mind, and voluntary power was altogether destroyed, so that the mouth-piece generally dropped from my unclosed lips.

Whenever the gas was in a high state of purity, it tasted distinctly sweet to the tongue and palate, and had an agreeable odour. I often thought that it produced a feeling somewhat analogous to taste, in its application to my lungs. In one or two experiments, I perceived a distinct sense of warmth in my chest.

I never felt from it any thing like oppressive respiration: my inspirations became deep in proportion as I

breathed it longer; but this phenomenon arose from increased energy of the muscles of respiration, and from a desire of increasing the pleasurable feelings.

Generally when I breathed from six to seven quarts, muscular motions were produced to a certain extent; sometimes I manifested my pleasure by stamping or laughing only; at other times, by dancing round the room and vociferating.

After the respiration of small doses, the exhilaration generally lasted for five or six minutes only. In one or two experiments when ten quarts had been breathed for near four minutes, an exhilaration and a sense of slight intoxication lasted for two or three hours.

On May 3d, to ascertain whether the gas would accelerate or retard the progress of sleep, I breathed at about 8 o'clock in the evening, 25 quarts of nitrous oxide, in quantities of six at a time, allowing but short intervals between each dose. The feelings were much less pleasurable than usual, and during the consumption of the two last doses, almost indifferent; indeed the gas was breathed rather too soon after its production, and contained some suspended acid vapour which stimulated the lungs so as to induce coughing.

After the experiments, for the first time I was somewhat depressed and debilitated; my propensity to sleep, however, came on at the usual hour, and as usual was indulged in, my repose was sound and unbroken.

Between May and July, I habitually breathed the gas, occasionally three or four times a day for a week together; at other periods, four or five times a week only.

The doses were generally from six to nine quarts; their effects appeared undiminished by habit, and were hardly ever exactly similar. Sometimes I had the feel-

ings of intense intoxication, attended with but little pleasure; at other times, sublime emotions connected with highly vivid ideas; my pulse was generally increased in fulness, but rarely in velocity.

The general effects of its operation upon my health and state of mind, are extremely difficult of description; nor can I well discriminate between its agency and that of other physical and moral causes.

I slept much less than usual, and previous to sleep, my mind was long occupied by visible imagery. I had a constant desire of action, a restlessness, and an uneasy feeling about the præcordia analogous to the sickness of hope.

But perhaps these phenomena in some measure depended on the interest and labour connected with the experimental investigation relating to the production of nitrous oxide, by which I was at this time incessantly occupied.

My appetite was as usual, and my pulse not materially altered. Sometimes for an hour after the inspiration of the gas, I experienced a species of mental indolence* pleasing rather than otherwise, and never ending in listlessness.

During the last week in which I breathed it uniformly, I imagined that I had increased sensibility of touch: my fingers were pained by any thing rough, and the tooth edge produced from slighter causes than usual. I was certainly more irritable, and felt more acutely from trifling circumstances. My bodily strength was rather diminished than increased.

* Mild physical pleasure is perhaps always destructive to action. Almost all our powerful voluntary actions, arise either from hope, fear, or desire; and the most powerful from desire, which is an emotion produced by the coalescence of hope or ideal pleasure with physical pain.

At the end of July, I left off my habitual course of respiration; but I continued occasionally to breathe the gas, either for the sake of enjoyment, or with a view of ascertaining its operation under particular circumstances.

In one instance, when I had head-ache from indigestion, it was immediately removed by the effects of a large dose of gas; though it afterwards returned, but with much less violence. In a second instance, a slighter degree of head-ache was wholly removed by two doses of gas.

The power of the immediate operation of the gas in removing intense physical pain, I had a very good opportunity of ascertaining.

In cutting one of the unlucky teeth called *dentes sapientiæ*, I experienced an extensive inflammation of the gum, accompanied with great pain, which equally destroyed the power of repose, and of consistent action.

On the day when the inflammation was most troublesome, I breathed three large doses of nitrous oxide. The pain always diminished after the first four or five inspirations; the thrilling came on as usual, and uneasiness was for a few minutes swallowed up in pleasure. As the former state of mind however returned, the state of organ returned with it; and I once imagined that the pain was more severe after the experiment than before.

In August, I made many experiments with a view of ascertaining whether any analogy existed between the sensible effects of the different gases which are sooner or later fatal to life when respired, and those of nitrous oxide.

I respired four quarts of hydrogen* nearly pure, pro-

* Pure hydrogen has been often respired by different philosophers, particularly by Scheele, Fontana, and the adventurous and unfortunate Rosier.

duced from zinc and muriatic acid, for near a minute, my lungs being previously exhausted and my nostrils carefully closed. The first six or seven inspirations produced no sensations whatever: in half a minute I perceived a disagreeable oppression of the chest, which obliged me to respire very quickly; this oppression gradually increased, till at last the pain of suffocation compelled me to leave off breathing. I felt no giddiness during or after the experiment; my pulse was rendered feebler and quicker; and a by-stander informed me that towards the last, my cheeks became purple.

In a second experiment, when the hydrogen was produced from iron and diluted sulphuric acid, I was unable to respire it for so long as three quarters of a minute; a transient giddiness and muscular debility were produced, the pulse was rendered very feeble, and the pain of suffocation was greater than before.

I breathed three quarts of nitrogen mingled with a very small portion of carbonic acid, for near a minute. It produced no alteration in my sensations for the first twenty seconds; then the painful sense of suffocation gradually came on, and increased rapidly in the last quarter of the minute, so as to oblige me to desist from the experiment. My pulse was rendered feebler and quicker. I felt no affection whatever in the head.

Mr. Watt's observations on the respiration of diluted hydrocarbonate by men, and Dr. Beddoes's experiments on the destruction of animals by pure hydrocarbonate, proved that its effects were highly deleterious.

As it destroyed life apparently by rendering the muscular fibre inirritable without producing any previous excitement, I was anxious to compare its sensible effects with those of nitrous oxide, which at this time I

believed to destroy life by producing the highest possible excitement, ending in lesion of organization.

In the first experiment, I breathed for near a minute three quarts of hydrocarbonate mingled with nearly two quarts of atmospheric air.* It produced a slight giddiness and pain in the head, and a momentary loss of voluntary power: my pulse was rendered much quicker and feebler. These effects, however, went off in five minutes, and I had no return of giddiness.

Emboldened by this trial, in which the feelings were not unlike those I experienced in the first experiments on nitrous oxide, I resolved to breathe pure hydrocarbonate.

For this purpose, I introduced into a silk bag four quarts of gas nearly pure, which was carefully produced from the decomposition of water by charcoal an hour before, and which had a very strong and disagreeable smell.

My friend, Mr. James Tobin, Jun. being present, after a forced exhaustion of my lungs, the nose being accurately closed, I made three inspirations and expirations of the hydrocarbonate. The first inspiration produced a sort of numbness and loss of feeling in the chest and about the pectoral muscles. After the second inspiration, I lost all power of perceiving external things, and had no distinct sensation except a terrible oppression on the chest. During the third expiration, this feeling disappeared, I seemed sinking into annihilation, and had just power enough to drop the mouth-piece from my unclosed lips. A short interval must have passed during which I respired common air, before the objects about me were distinguishable. On recollecting

* I believe it had never been breathed before by any individual, in a state so little diluted.

myself, I faintly articulated, "*I do not think I shall die.*" Putting my finger on the wrist, I found my pulse thread-like and beating with excessive quickness.

In less than a minute, I was able to walk, and the painful oppression on the chest directed me to the open air.

After making a few steps which carried me to the garden, my head became giddy, my knees trembled, and I had just sufficient voluntary power to throw myself on the grass. Here the painful feeling of the chest increased with such violence as to threaten suffocation. At this moment, I asked for some nitrous oxide. Mr. Dwyer brought me a mixture of oxygen and nitrous oxide. I breathed this for a minute, and *believed* myself relieved. In five minutes, the painful feelings began gradually to diminish. In an hour they had nearly disappeared, and I felt only excessive weakness and a slight swimming of the head. My voice was very feeble and indistinct. This was at two o'clock in the afternoon.

I afterwards walked slowly for about half an hour, with Mr. Tobin, Jun. and on my return, was so much stronger and better, as to believe that the effects of the gas had disappeared; though my pulse was 120, and very feeble. I continued without pain for near three quarters of an hour, when the giddiness returned with such violence as to oblige me to lie on the bed; it was accompanied with nausea, loss of memory, and deficient sensation. In about an hour and half, the giddiness went off, and was succeeded by an excruciating pain in the forehead and between the eyes, with transient pains in the chest and extremities.

Towards night these affections gradually diminished. At ten,* no disagreeable feeling except weakness re-

* I ought to observe, that between eight and ten, I took, by the advice of Dr. Beddoes, two or three doses of diluted nitric acid.

mained. I slept sound, and awoke in the morning very feeble and very hungry. No recurrence of the symptoms took place, and I had nearly recovered my strength by the evening.

I have been minute in the account of this experiment, because it proves, that hydrocarbonate acts as a sedative, i. e. that it produces diminution of vital action, and debility, without previously exciting. There is every reason to believe, that if I had taken four or five inspirations instead of three, they would have destroyed life immediately without producing any painful sensation. Perhaps most of the uneasy feelings after the experiment, were connected with the return of the healthy condition of organs.*

About a week after this experiment, I attempted to respire carbonic acid, not being at the time acquainted with the experiments of Rosier.

I introduced into a silk bag four quarts of well washed carbonic acid produced from carbonate of ammonia† by heat, and after a complete voluntary exhaustion of my lungs, attempted to inspire it. It tasted strongly acid in the mouth and fauces, and produced a sense of burning at the top of the uvula. In vain I made powerful voluntary efforts to draw it into the windpipe; at the moment that the epiglottis was raised a little, a painful stimulation was induced, so as to close it spasmodically on the glottis; and thus in repeated trials

* By whatever cause the exhaustion of organs is produced, pain is almost uniformly connected with their returning health. Pain is rarely ever perceived in limbs debilitated by fatigue till after they have been for some hours at rest. Pain is uniformly connected with the recovery from the debility induced by typhus, often with the recovery from that produced by the stimulation of opium and alcohol.

† Carbonic acid is produced in this way in a high state of purity, and with great readiness.

I was prevented from taking a single particle of carbonic acid into my lungs.

I tried to breathe a mixture of two quarts of common air and three of carbonic acid, without success; it stimulated the epiglottis nearly in the same manner as pure carbonic acid, and was perfectly non-respirable.

I found that a mixture of three quarts of carbonic acid with seven of common air was respirable, I breathed it for near a minute. At the time, it produced a slight degree of giddiness, and an inclination to sleep. These effects, however, very rapidly disappeared after I had ceased to breathe,* and no other affections followed.

During the course of experiments on nitrous oxide, I several times breathed oxygen procured from manganese by heat, for from three to five minutes.

In respiring eight or ten quarts; for the first two or three minutes I could perceive no effects. Towards the end, even when I breathed very slowly, my respiration became oppressed, and I felt a sensation analogous to that produced by the want of fresh air; though but little of the oxygen had been consumed.

In one experiment when I breathed from and into a bag containing 20 quarts of oxygen for near six minutes, Dr. Kinglake felt my pulse, and found it not altered in velocity, but rather harder than before. I perceived no effects but those of oppression on the chest.†

* Carbonic acid possesses no action on arterial blood. Hence perhaps its slight effects when breathed mingled with large quantities of common air. Its effects are very marked upon venous blood! If it were thrown forcibly into the lungs of animals, the momentary application of it to the pulmonary venous blood would probably destroy life.

† In a conversation with Mr. Watt, relating to the powers of gases, that excellent philosopher told me he had for some time entertained a suspicion, that the effects attributed to oxygen produced from manganese by heat, in some measure depended upon nitrous acid suspended in

Having observed in my experiments upon venous blood, that nitrous gas rendered that fluid of a purple tinge, very like the colour generated in it by nitrous oxide; and finding no painful effects produced by the application of nitrous gas to the bare muscular fibre, I began to imagine that this gas might be breathed with impunity, provided it were possible in any way to free the lungs of common air before inspiration, so as to prevent the formation of nitrous acid.

On this supposition, during a fit of enthusiasm produced by the respiration of nitrous oxide, I resolved to endeavour to breathe nitrous gas.

114 cubic inches of nitrous gas were introduced into the large mercurial air-holder; two small silk bags of the capacity of seven quarts were filled with nitrous oxide.

After a forced exhaustion of my lungs, my nose being accurately closed, I made three inspirations and expirations of nitrous oxide in one of the bags, to free my lungs as much as possible from atmospheric oxygen; then, after a full expiration of the nitrous oxide, I transferred my mouth from the mouth-piece of the bag to that of the air-holder, and turning the stop-cock, attempted to inspire the nitrous gas. In passing

the gas, formed during ignition by the union of some of the oxygen of the manganese with nitrogen likewise condensed in it.

In the course of experiments on nitrous acid, detailed in Research I. made in September, October, and December, 1790, I several times experienced a severe oppression on the chest and difficulty of respiration, not unanalogous to that produced by oxygen, but much more violent, from breathing an atmosphere loaded with nitrous acid vapour. This fact seemed to confirm Mr. Watt's suspicion. I confess, however, that I have never been able to detect any smell of nitrous acid, either by means of my own organs or those of others, during the production of oxygen; when the gas is suffered to pass into the atmosphere. The oxygen breathed in the experiments detailed in the text, had been for some days in contact with water.

through my mouth and fauces, it tasted astringent and highly disagreeable; it occasioned a sense of burning in the throat, and produced a spasm of the epiglottis so painful as to oblige me to desist instantly from attempts to inspire it. After moving my lips from the mouth-piece, when I opened them to inspire common air, aëriform nitrous acid was instantly formed in my mouth, which burnt the tongue and palate, injured the teeth, and produced an inflammation of the mucous membrane which lasted some hours.

As after the respiration of nitrous oxide in the experiments in the last Research, a small portion of the residual atmospheric air remained in the lungs, mingled with the gas, after forced expiration; it is most probable that a minute portion of nitrous acid was formed in this experiment, when the nitrous gas was taken into the mouth and fauces, which might produce its stimulating properties. If so, perhaps I owe my life to the circumstance; for supposing I had taken an inspiration of nitrous gas, and even that it had produced no positive effects, it is highly improbable, that by breathing nitrous oxide, I should have freed my lungs from it, so as to have prevented the formation of nitrous acid when I again inspired common air. I never design again to attempt so rash an experiment.

In the beginning of September I often respired nitrous oxide mingled with different proportions of common air or oxygen. The effects produced by the diluted gas were much less violent than those produced by pure nitrous oxide. They were generally pleasant: the thrilling was not often perceived, but a sense of exhilaration was almost constant.

Between September and the end of October, I made but few experiments on respiration, almost the whole of

my time being devoted to chemical experiments on the production and analysis of nitrous oxide.

At this period my health being somewhat injured by the constant labour of experimenting, and the perpetual inhalation of the acid vapours of the laboratory, I went into Cornwall; where new associations of ideas and feelings, common exercise, a pure atmosphere, luxurious diet and moderate indulgence in wine, in a month restored me to health and vigour.

Nov. 27th; immediately after my return, being fatigued by a long journey, I respired nine quarts of nitrous oxide, having been precisely thirty-three days without breathing any. The feelings were different from those I had experienced in former experiments. After the first six or seven inspirations, I gradually began to lose the perception of external things, and a vivid and intense recollection of some former experiments passed through my mind, so that I called out "*what an amazing concatenation of ideas!*" I had no pleasurable feeling whatever, I used no muscular motion, nor did I feel any disposition to it; after a minute, when I made the note of the experiment, all the uncommon sensations had vanished; they were succeeded by a slight soreness in one of the arms and in the leg: in three minutes these affections likewise disappeared.

From this experiment I was inclined to suppose that my newly acquired health had diminished my susceptibility to the effects of the gas. About ten days after, however, I had an opportunity of proving the fallacy of this supposition.

Immediately after a journey of 126 miles, in which I had no sleep the preceding night, being much exhausted, I respired seven quarts of gas for near three minutes.

It produced the usual pleasurable effects, and slight muscular motion. I continued exhilarated for some minutes afterwards: but in half an hour found myself neither more nor less exhausted than before the experiment. I had a great propensity to sleep.

I repeated the experiment four or five times in the following week, with similar effects. My susceptibility was certainly not diminished. I even thought that I was more affected than formerly by equal doses.

Though, except in one instance, when indeed the gas was impure, I had experienced no decisive exhaustion after excitement from nitrous oxide, yet still I was far from being satisfied that it was unanalogous to stimulants in general. No experiment had been made in which the excitement from nitrous oxide had been kept up for so great a length of time and carried to so great an extent as that in which it is uniformly succeeded by excessive debility under the agency of other powers.

It occurred to me, that supposing nitrous oxide to be a stimulant of the common class, it would follow that the debility produced in consequence of excessive stimulation by a known agent, ought to be *increased* after excitement from nitrous oxide.*

To ascertain whether this was the case, I made, on December 23d, at four P.M. the following experiment. I drank a bottle of wine in large draughts in less than eight minutes. Whilst I was drinking, I perceived a sense of fulness in the head, and throbbing of the arteries, not unanalogous to that produced in the first stage of nitrous oxide excitement. After I had finished the bottle, this fulness increased, the objects around me

* In the same manner as the debility from intoxication by two bottles of wine is increased by a third.

became dazzling, the power of distinct articulation was lost, and I was unable to walk steadily. At this moment the sensations were rather pleasurable than otherwise, the sense of fulness in the head soon however increased so as to become painful, and in less than an hour I sunk into a state of insensibility.*

In this situation I must have remained for two hours or two hours and a half.

I was awakened by head-ache and painful nausea. The nausea continued even after the contents of the stomach had been ejected. The pain in the head every minute increased; I was neither feverish nor thirsty; my bodily and mental debility were excessive, and the pulse feeble and quick.

In this state I breathed for near a minute and half five quarts of gas, which was brought to me by the operator for nitrous oxide; but as it produced no sensations whatever, and apparently rather increased my debility, I am almost convinced that it was from some accident, either common air, or very impure nitrous oxide.

Immediately after this trial, I respired 12 quarts of oxygen for near four minutes. It produced no alteration in my sensations at the time; but immediately after I imagined that I was a little exhilarated.

The head-ache and debility still however continuing with violence, I examined some nitrous oxide which had been prepared in the morning, and finding it very pure, respired seven quarts of it for two minutes and half.

* I ought to observe that my usual drink is water, that I had been little accustomed to take wine or spirits, and had never been completely intoxicated but once before in the course of my life. This will account for the powerful effects of a single bottle of wine.

I was unconscious of head-ache after the third inspiration; the usual pleasurable thrilling was produced, voluntary power was destroyed, and vivid ideas rapidly passed through my mind; I made strides across the room, and continued for some minutes much exhilarated. Immediately after the exhilaration had disappeared, I felt a slight return of the head-ache; it was connected with transient nausea. After two minutes, when a small quantity of acidified wine had been thrown from the stomach, both the nausea and head-ache disappeared; but languor and depression not very different in degree from those existing before the experiment, succeeded. They, however, gradually went off before bed time. I slept sound the whole of the night except for a few minutes, during which I was kept awake by a trifling head-ache. In the morning, I had no longer any debility. No head-ache or giddiness came on after I had arisen, and my appetite was very great.

This experiment proved, that debility from intoxication was not increased by excitement from nitrous oxide. The head-ache and depression, it is probable, would have continued longer if it had not been administered. Is it not likely that the slight nausea following the effects of the gas was produced by new excitability given to the stomach?

To ascertain with certainty, whether the most extensive action of nitrous oxide compatible with life, was capable of producing debility, I resolved to breathe the gas for such a time and in such quantities, as to produce excitement equal in duration and superior in intensity to that occasioned by high intoxication from opium or alcohol.

To habituate myself to the excitement, and to carry it on gradually, on December 26th, I was inclosed

in an air-tight breathing-box,* of the capacity of about 9 cubic feet and half, in the presence of Dr. Kinglake.

After I had taken a situation in which I could by means of a curved thermometer inserted under the arm, and a stop-watch, ascertain the alterations in my pulse and animal heat, 20 quarts of nitrous oxide were thrown into the box.

For three minutes I experienced no alteration in my sensations, though immediately after the introduction of the nitrous oxide the smell and taste of it were very evident.†

In four minutes I began to feel a slight glow in the cheeks, and a generally diffused warmth over the chest, though the temperature of the box was not quite 50°. I had neglected to feel my pulse before I went in; at this time it was 104 and hard, the animal heat was 98°. In ten minutes the animal heat was near 99°, in a quarter of an hour 99·5°, when the pulse was 102, and fuller than before.

At this period 20 quarts more of nitrous oxide were thrown into the box, and well mingled with the mass of air by agitation.

In 25 minutes the animal heat was 100°, pulse 124. In 30 minutes, 20 quarts more of gas were introduced.

My sensations were now pleasant; I had a generally diffused warmth without the slightest moisture of the skin, a sense of exhilaration similar to that produced by

* The plan of this box was communicated by Mr. Watt. An account of it will be detailed in the *Researches*.

† The nitrous oxide was too diluted to act much; it was mingled with near 22 times its bulk of atmospheric air.

a small dose of wine, and a disposition to muscular motion and to merriment.

In three quarters of an hour the pulse was 104, and animal heat not quite 99.5° , the temperature of the chamber was 64° . The pleasurable feelings continued to increase, the pulse became fuller and slower, till in about an hour it was 88° , when the animal heat was 99° .

20 quarts more of air were admitted. I had now a great disposition to laugh; luminous points seemed frequently to pass before my eyes, my hearing was certainly more acute, and I felt a pleasant lightness and power of exertion in my muscles. In a short time the symptoms became stationary; breathing was rather oppressed, and on account of the great desire of action, rest was painful.

I now came out of the box, having been in precisely an hour and quarter.

The moment after, I began to respire 20 quarts of unmingled nitrous oxide. A thrilling, extending from the chest to the extremities, was almost immediately produced. I felt a sense of tangible extension highly pleasurable in every limb; my visible impressions were dazzling, and apparently magnified, I heard distinctly every sound in the room, and was perfectly aware of my situation.* By degrees, as the pleasurable sensations increased, I lost all connection with external things; trains of vivid visible images rapidly passed through my mind, and were connected with words in such a manner, as to produce perceptions perfectly novel. I existed in a world of newly connected and newly modified ideas. I theorised—I imagined that I made discoveries. When I was awakened from this

* In all these experiments, after the first minute, my cheeks became purple.

semi-delirious trance by Dr. Kinglake, who took the bag from my mouth, indignation and pride were the first feelings produced by the sight of the persons about me. My emotions were enthusiastic and sublime; and for a minute I walked round the room, perfectly regardless of what was said to me. As I recovered my former state of mind, I felt an inclination to communicate the discoveries I had made during the experiment. I endeavoured to recall the ideas, they were feeble and indistinct; one collection of terms, however, presented itself: and with the most intense belief and prophetic manner, I exclaimed to Dr. Kinglake, "*Nothing exists but thoughts!—the universe is composed of impressions, ideas, pleasures and pains!*"

About three minutes and half only had elapsed during this experiment, though the time as measured by the relative vividness of the recollected ideas, appeared to me much longer.

Not more than half of the nitrous oxide was consumed. After a minute, before the thrilling of the extremities had disappeared, I breathed the remainder. Similar sensations were again produced; I was quickly thrown into the pleasurable trance, and continued in it longer than before. For many minutes after the experiment, I experienced the thrilling in the extremities, the exhilaration continued nearly two hours. For a much longer time I experienced the mild enjoyment before described connected with indolence; no depression or feebleness followed. I ate my dinner with great appetite and found myself lively and disposed to action immediately after. I passed the evening in executing experiments. At night I found myself unusually cheerful and active; and the hours between eleven and two, were spent in copying the foregoing detail from

the common-place book, and in arranging the experiments. In bed I enjoyed profound repose. When I awoke in the morning, it was with consciousness of pleasurable existence, and this consciousness more or less continued through the day.

Since December, I have very often breathed nitrous oxide. My susceptibility to its power is rather increased than diminished. I find six quarts a full dose, and I am rarely able to respire it in any quantity for more than two minutes and half.

The mode of its operation is somewhat altered. It is indeed very different at different times.

I am scarcely ever excited into violent muscular action; the emotions are generally much less intense and sublime than in the former experiments, and not often connected with thrilling in the extremities.

When troubled with indigestion, I have been two or three times unpleasantly affected after the excitement of the gas. Cardialgia, eructations, and unpleasant fullness of the head were produced.

I have often felt very great pleasure when breathing it alone, in darkness and silence, occupied only by ideal existence. In two or three instances when I have breathed it amidst noise, the sense of hearing has been painfully affected even by moderate intensity of sound. The light of the sun has sometimes been disagreeably dazzling. I have once or twice felt an uneasy sense of tension in the cheeks and transient pains in the teeth.

Whenever I have breathed the gas after excitement from moral or physical causes, the delight has been often intense and sublime.

On May 5th, at night, after walking for an hour amidst the scenery of the Avon, at this period rendered exquisitely beautiful by bright moonshine; my mind

being in a state of agreeable feeling, I respired six quarts of newly prepared nitrous oxide.

The thrilling was very rapidly produced. The objects around me were perfectly distinct, and the light of the candle not as usual dazzling. The pleasurable sensation was at first local, and perceived in the lips and about the cheeks. It gradually, however, diffused itself over the whole body, and in the middle of the experiment was for a moment so intense and pure as to absorb existence. At this moment, and not before, I lost consciousness; it was, however, quickly restored, and I endeavoured to make a by-stander acquainted with the pleasure I experienced by laughing and stamping. I had no vivid ideas. The thrilling and the pleasurable feeling continued for many minutes; I felt two hours afterwards, a slight recurrence of them, in the intermediate state between sleeping and waking; and I had during the whole of the night, vivid and agreeable dreams. I awoke in the morning with the feeling of restless energy, or that desire of action connected with no definite object, which I had often experienced in the course of experiments in 1799.

I have two or three times since respired nitrous oxide under similar circumstances; but never with equal pleasure.

During the last fortnight, I have breathed it very often; the effects have been powerful and the sensations uncommon; but pleasurable only in a slight degree.

I ought to have observed that a desire to breathe the gas is always awakened in me by the sight of a person breathing, or even by that of an air-bag or an air-holder.

I have this day, June 5th, respired four large doses of gas. The first two taken in the morning acted very

powerfully; but produced no thrilling nor other pleasurable feelings. The effects of the third, breathed immediately after a hearty dinner, were pleasant, but neither intense nor intoxicating. The fourth was respired at night in darkness and silence after the occurrence of a circumstance which had produced some anxiety. This dose affected me powerfully and pleasantly; a slight thrilling in the extremities was produced; an exhilaration continued for some time, and I have had but little return of uneasiness; (11 P.M.)

From the nature of the language of feeling, the preceding detail contains many imperfections; I have endeavoured to give as accurate an account as possible of the strange effects of nitrous oxide, by making use of terms standing for the most similar common feelings.

We are incapable of recollecting pleasures and pains of sense.* It is impossible to reason concerning them,

* Physical pleasure and pain generally occur connected with a compound impression, i. e. an organ and some object. When the idea left by the compound impression, is called up by being linked accidentally to some other idea or impression, no recurrence, or the slightest possible, of the pleasure or pain in any form will take place. But when the compound impression itself exists *without* the physical pleasure or pain, it will awaken ideal or intellectual pleasure or pain, i. e. hope or fear. So that physical pleasure and pain are to hope and fear, what impressions are to ideas. For instance, assuming no accidental association, the child does not fear the fire before he is burnt. When he puts his finger to the fire he feels the physical pain of burning, which is connected with a visible compound impression, the fire and his finger. Now when the compound idea of the fire and his finger, left by the compound impression are called up by his mother, saying, "*You have burnt your finger,*" nothing like fear or the pain of burning is connected with it. But when the finger is brought near the fire, i. e. when the compound impression again exists, the ideal pain of burning or the passion of fear is awakened, and it becomes connected with those very actions which removed the finger from the fire.

except by means of terms which have been associated with them at the moment of their existence, and which are afterwards called up amidst trains of concomitant ideas.

When pleasures or pains are new or connected with new ideas, they can never be intelligibly detailed unless associated during their existence with terms standing for analogous feelings.

I have sometimes experienced from nitrous oxide, sensations similar to no others, and they have consequently been indescribable. This has been likewise often the case with other persons. Of two paralytic patients who were asked what they felt after breathing nitrous oxide, the first answered, "*I do not know how, but very queer.*" The second said, "*I felt like the sound of a harp.*" Probably in the one case, no analogous feelings had ever occurred. In the other, the pleasurable thrillings were similar to the sensations produced by music; and hence, they were connected with terms formerly applied to music.

DIVISION II.

DETAILS OF THE EFFECTS PRODUCED BY THE RESPIRATION OF NITROUS OXIDE UPON DIFFERENT INDIVIDUALS, FURNISHED BY THEMSELVES.

THE experiments related in the following details, were made in the Medical Pneumatic Institution.

Abstracts from many of them have been published by Dr. Beddoes.*

* Notice of some Observations made at the Medical Pneumatic Institution.

I. *Detail of Mr. J. W. TOBIN.*

Having seen the remarkable effects produced on Mr. Davy, by breathing nitrous oxide, the 18th of April; I became desirous of taking some. A day or two after, I breathed 2 quarts of this gas, returning it back again into the same bag; after two or three inspirations, breathing became difficult, and I occasionally admitted common air into my lungs. While the respiration was continued, my sensations became more pleasant. On taking the bag from my mouth, I staggered a little, but felt no other effect.

On the second time of making the experiment, I took nearly 4 quarts, but still found it difficult to continue breathing long, though the air which was left in the bag was far from being impure.

The effects, however, in this case, were more striking than in the former. Increased muscular action was accompanied by very pleasurable feelings, and a strong desire to continue the inspiration. On removing the bag from my mouth, I laughed, staggered, and attempted to speak, but stammered exceedingly, and was utterly unable to pronounce some words. My usual state of mind, however, soon returned.

On the 29th, I again breathed 4 quarts. The pleasant feelings produced at first, urged me to continue the inspiration with great eagerness. These feelings, however, went off towards the end of the experiment, and no other effects followed. The gas had probably been breathed too long, as it would not support flame. I then proposed to Mr. Davy, to inhale the air by the mouth from one bag, and to expire it from the nose into another. This method was pursued with less than

3 quarts, but the effects were so powerful as to oblige me to take in a little common air occasionally. I soon found my nervous system agitated by the highest sensations of pleasure, which are difficult of description; my muscular powers were very much increased, and I went on breathing with great vehemence, not from a difficulty of inspiration, but from an eager avidity for more air. When the bags were exhausted and taken from me, I continued breathing with the same violence; then suddenly starting from the chair, and vociferating with pleasure, I made towards those that were present, as I wished they should participate in my feelings. I struck gently at Mr. Davy; and a stranger entering the room at the moment, I made towards him, and gave him several blows, but more in the spirit of good humour than of anger. I then ran through different rooms in the house, and at last returned to the laboratory somewhat more composed; my spirits continued much elevated for some hours after the experiment, and I felt no consequent depression either in the evening or the day following, but slept as soundly as usual.

On the 5th of May, I again attempted to breathe nitrous oxide, but it happened to contain suspended nitrous vapour which rendered it non-respirable.

On the 7th, I inspired 7 quarts of pure gas mingled with an equal quantity of common air; the sensations were pleasant, and my muscular power much increased.

On the 8th, I inspired five quarts without any mixture of common air, but the effects were not equal to those produced the day before; indeed there were reasons for supposing that the gas was impure.

On the 18th, I breathed nearly 6 quarts of the pure nitrous oxide. It is not easy to describe my sensations; they were superior to any thing I ever before experi-

enced. My step was firm, and all my muscular powers increased. My senses were more alive to every surrounding impression; I threw myself into several theatrical attitudes, and traversed the laboratory with a quick step; my mind was elevated to a most sublime height. It is giving but a faint idea of the feelings to say, that they resembled those produced by a representation of an heroic scene on the stage, or by reading a sublime passage in poetry when circumstances contribute to awaken the finest sympathies of the soul. In a few minutes the usual state of mind returned. I continued in good spirits for the rest of the day, and slept soundly.

Since the 18th of May, I have very often breathed nitrous oxide. In the first experiments, when pure, its effects were generally similar to those just described.

Lately I have seldom experienced vivid sensations. The pleasure produced by it is slight and tranquil, I rarely feel sublime emotions or increased muscular power.

J. W. TOBIN.

October, 1799.

II. *Detail of* MR. WM. CLAYFIELD.

The first time that I breathed the nitrous oxide, it produced feelings analogous to those of intoxication. I was for some time unconscious of existence, but at no period of the experiment experienced agreeable sensations; a momentary nausea followed it, but unconnected with languor or head-ache.

After this I several times respired the gas, but on account of the fulness in the head and apparent throbbing

bing of the arteries in the brain,* always desisted to breathe before the full effects were produced. In two experiments, however, when by powerful voluntary efforts I succeeded in breathing a large quantity of gas for some minutes, I had highly pleasurable thrillings in the extremities, and such increase of muscular power, as to be obliged to exert my limbs with violence. After these experiments, no languor or depression followed.

WILLIAM CLAYFIELD.

III. *Letter from* DR. KINGLAKE.

In compliance with your desire, I will endeavour to give you a faithful detail of the effects produced on my sensations by the inhalation of nitrous oxide.

My first inspiration of it was limited to four quarts, diluted with an equal quantity of atmospheric air. After a few inspirations, a sense of additional freedom and power (call it energy if you please) agreeably pervaded the region of the lungs; this was quickly succeeded by an almost delirious but highly pleasurable sensation in the brain, which was soon diffused over the whole frame, imparting to the muscular power at once an increased disposition and tone for action; but the mental effect of the excitement was such as to absorb in a sort of intoxicating placidity, and delight, volition, or rather the power of voluntary motion. These effects were in a greater or less degree protracted during about five minutes, when the former state returned, with the difference however of feeling more cheerful and alert, for several hours after.

It seemed also to have had the further effect of reviv-

* In some of these experiments, hearing was rendered more acute.

ing rheumatic irritations in the shoulder and knee-joints, which had not been previously felt many months. No perceptible change was induced in the pulse either at or subsequent to the time of inhaling the gas.

The effects produced by a second trial of its powers, were more extensive, and concentrated on the brain. In this instance, nearly 6 quarts undiluted, were accurately and fully inhaled. As on the former occasion, it immediately proved agreeably respirable, but before the whole quantity was quite exhausted, its agency was exerted so strongly on the brain, as progressively to suspend the senses of seeing, hearing, feeling, and ultimately of power of volition itself. At this period, the pulse was much augmented both in force and frequency; slight convulsive twitches of the muscles of the arms were also induced; no painful sensation, nausea, or languor, however, either preceded, accompanied, or followed this state, nor did a minute elapse before the brain rallied, and resumed its wonted faculties, when a sense of glowing warmth extending over the system, was speedily succeeded by a reinstatement of the equilibrium of health.

The more permanent effects were (as in the first experiment) an invigorated feel of vital power, improved spirits, transient irritations in different parts, but not so characteristically rheumatic as in the former instance.

Among the circumstances most worthy of regard in considering the properties and administration of this powerful aërial agent, may be ranked, the fact of its being (contrary to the prevailing opinion*) both highly

* Dr. Mitchill (an American chemist) has erroneously supposed its full admission to the lungs, in its concentrated state, to be incompatible with animal life, and that in a more diluted form it operates as a principal agent in the production of contagious diseases, &c. This gratuitous

respirable, and salutary; that it impresses the brain and system at large with a more or less strong and durable degree of pleasurable sensation; that unlike the effect of other violently exciting agents, no sensible exhaustion nor diminution of vital power accrues from the exertions of its stimulant property; that its most excessive operation even, is neither permanently nor transiently debilitating; and finally, that it fairly promises, under judicious application, to prove an extremely efficient remedy, as well in the vast tribe of diseases originating from deficient irritability and sensibility, as in those proceeding from morbid associations, and modifications, of those vital principles.

If you should deem any thing contained in this cursory narrative capable of subserving in any degree the practical advantages likely to result from your scientific and valuable investigation of the genuine properties of the nitrous oxide, it is perfectly at your disposal.

I am,

Your sincere friend,

ROBERT KINGLAKE.

To Mr. DAVY.

Bristol, June 14th, 1799.

IV. *Detail of Mr. SOUTHEY.*

In breathing the nitrous oxide, I could not distinguish between the first feelings it occasioned and an apprehension is thus unqualifiedly affirmed. "If a full inspiration of gaseous oxide be made, there will be a sudden extinction of life; and this accordingly accounts for the fact related by Russel (*History of Aleppo*, p. 232.) and confirmed by other observers, of many persons falling down dead suddenly, when struck with the contagion of the plague."

Vide *Remarks on the Gaseous Oxide of Azote*, by Samuel Latham Mitchill, M.D.

hension of which I was unable to divest myself. My first definite sensation was a dizziness, a fulness in the head, such as to induce a fear of falling. This was momentary. When I took the bag from my mouth, I immediately laughed. The laugh was involuntary but highly pleasurable, accompanied by a thrill all through me; and a tingling in my toes and fingers, a sensation perfectly new and delightful. I felt a fulness in my chest afterwards; and during the remainder of the day, imagined that my taste and hearing were more than commonly quick. Certain I am that I felt myself more than usually strong and cheerful.

In a second trial, by continuing the inhalation longer, I felt a thrill in my teeth; and breathing still longer the third time, became so full of strength as to be compelled to exercise my arms and feet.

Now after an interval of some months, during which my health has been materially impaired, the nitrous oxide produces an effect upon me totally different. Half the quantity affects me, and its operation is more violent; a slight laughter is first induced,* and a desire to continue the inhalation, which is counteracted by fear from the rapidity of respiration; indeed my breath becomes so short and quick, that I have no doubt but the quantity which I formerly breathed would now destroy me. The sensation is not painful, neither is it in the slightest degree pleasurable.

ROBERT SOUTHEY.

* In the former experiments, Mr. Southey generally respired six quarts, now he is unable to consume two.

In an experiment made since this paper was drawn up, the effect was rather pleasurable.

V. *Letter from DR. ROGET.*

The effect of the inspirations of the nitrous oxide was that of making me vertiginous, and producing a tingling sensation in my hands and feet: as these feelings increased, I seemed to lose the sense of my own weight, and imagined I was sinking into the ground. I then felt a drowsiness gradually steal upon me, and a disinclination to motion; even the actions of inspiring and expiring were not performed without effort: and it also required some attention of mind to keep my nostrils closed with my fingers. I was gradually roused from this torpor by a kind of delirium, which came on so rapidly that the air-bag dropped from my hands. This sensation increased for about a minute after I had ceased to breathe, to a much greater degree than before, and I suddenly lost sight of all the objects around me, they being apparently obscured by clouds, in which were many luminous points, similar to what is often experienced on rising suddenly and stretching out the arms, after sitting long in one position.

I felt myself totally incapable of speaking, and for some time lost all consciousness of where I was, or who was near me. My whole frame felt as if violently agitated: I thought I panted violently: my heart seemed to palpitate, and every artery to throb with violence; I felt a singing in my ears; all the vital motions seemed to be irresistibly hurried on, as if their equilibrium had been destroyed, and every thing was running headlong into confusion. My ideas succeeded one another with extreme rapidity, thoughts rushed like a torrent through my mind, as if their velocity had been suddenly accelerated by the bursting of a barrier which had before re-

tained them in their natural and equable course. This state of extreme hurry, agitation, and tumult, was but transient. Every unnatural sensation gradually subsided; and in about a quarter of an hour after I had ceased to breathe the gas, I was nearly in the same state in which I had been at the commencement of the experiment.

I cannot remember that I experienced the least pleasure from any of these sensations. I can, however, easily conceive, that by frequent repetition I might reconcile myself to them, and possibly even receive pleasure from the same sensations which were then unpleasant.

I am sensible that the account I have been able to give of my feelings is very imperfect. For however calculated their violence and novelty were to leave a lasting impression on the memory, these circumstances were for that very reason unfavourable to accuracy of comparison with sensations already familiar.

The nature of the sensations themselves which bore greater resemblance to a half delirious dream than to any distinct state of mind capable of being accurately remembered, contributes very much to increase the difficulty. And as it is above two months since I made the experiment, many of the minuter circumstances have probably escaped me. I remain

Yours, &c.

P. ROGET.

TO MR. DAVY.

VI. *Letter from MR. JAMES THOMSON.*

The first time I respired nitrous oxide, the experiment was made under a strong impression of fear, and

the quantity I breathed not sufficient, as you informed me, to produce the usual effect. I did not note very accurately my sensations. I remember I experienced a slight degree of vertigo after the third or fourth inspiration; and breathed with increased vigour, my inspirations being much deeper and more vehement than ordinary. I was enabled, the next time I made the experiment, to attend more accurately to my sensations, and you have the observations I made on them at the time.

After the fourth inspiration, I experienced the same increased action of the lungs, as in the former case. My inspirations became uncommonly full and strong, attended with a thrilling sensation about the chest, highly pleasurable, which increased to such a degree as to induce a fit of involuntary laughter, which I in vain endeavoured to repress. I felt a slight giddiness which lasted for a few moments only. My inspirations now became more vehement and frequent; and I inhaled the air with an avidity strongly indicative of the pleasure I received. That peculiar thrill which I had at first experienced at the chest, now pervaded my whole frame; and during the two or three last inspirations, was attended with a remarkable tingling in my fingers and toes. My feelings at this moment are not to be described: I felt a high, an extraordinary degree of pleasure, different from that produced by wine, being divested of all its gross accompaniments, and yet approaching nearer to it than to any other sensation I am acquainted with.

I am certain that my muscular strength was for a time much increased. My disposition to exert it was such as I could not repress, and the satisfaction I felt in any violent exertion of my legs and arms is hardly to be con-

ceived. These vivid sensations were not of long duration; they diminished insensibly, and in little more than a quarter of an hour I could perceive no difference between the state I was then in, and that previous to the respiration of the air.

The observations I made on repeating the experiment, do not differ from the preceding, except in the circumstance of the involuntary laughter, which I never afterwards experienced, though I breathed the air several times; and in the following curious fact, which, as it was dependent on circumstances, did not always occur.

Having respired the same quantity of air as usual, and with precisely the same effects, I was surprised to find myself affected a few minutes afterwards with the recurrence of a pain in my back and knees, which I had experienced the preceding day from fatigue in walking. I was rather inclined to deem this an accidental coincidence than an effect of the air; but the same thing constantly occurring whenever I breathed the air, shortly after suffering pain either from fatigue, or any other accidental cause, left no doubt on my mind as to the accuracy of the observation.

I have now given you the substance of the notes I made whilst the impressions were strong on my mind. I cannot add anything from recollection that will at all add to the accuracy of this account, or assist those who have not respired this air, in forming a clearer idea of its extraordinary effects. It is extremely difficult to convey to others by means of words, any idea of particular sensations, of which they have had no experience. It can only be done by making use of such terms as are expressive of sensations that resemble them, and in these our vocabulary is very defective. To be able at all to comprehend the effects of nitrous oxide, it is

necessary to respire it, and after that, we must either invent new terms to express these new and particular sensations, or attach new ideas to old ones, before we can communicate intelligibly with each other on the operation of this extraordinary gas.

I am, &c.

JAMES THOMSON.

TO MR. DAVY.

London, Sept. 21st, 1799.

VII. *Detail of MR. COLERIDGE.*

The first time I inspired the nitrous oxide, I felt a highly pleasurable sensation of warmth over my whole frame, resembling that which I remember once to have experienced after returning from a walk in the snow into a warm room. The only motion which I felt inclined to make, was that of laughing at those who were looking at me. My eyes felt distended, and towards the last, my heart beat as if it were leaping up and down. On removing the mouth-piece, the whole sensation went off almost instantly.

The second time I felt the same pleasurable sensation of warmth, but not, I think, in quite so great a degree. I wished to know what effect it would have on my impressions; I fixed my eye on some trees in the distance, but I did not find any other effect except that they became dimmer and dimmer, and looked at last as if I had seen them through tears. My heart beat more violently than the first time. This was after a hearty dinner.

The third time I was more violently acted on than in the two former. Towards the last, I could not avoid, nor indeed felt any wish to avoid, beating the

ground with my feet; and after the mouth-piece was removed, I remained for a few seconds motionless, in great extacy.

The fourth time was immediately after breakfast. The few first impressions affected me so little, that I thought Mr. Davy had given me atmospheric air: but soon felt the warmth beginning about my chest, and spreading upward and downward, so that I could feel its progress over my whole frame. My heart did not beat so violently; my sensations were highly pleasurable, not so intense or apparently local, but of more unmingled pleasure than I had ever before experienced.*

S. T. COLERIDGE.

VIII. *Detail of MR. WEDGWOOD.*

July 23, I called on Mr. Davy at the Medical Institution, who asked me to breathe some of the nitrous oxide, to which I consented, being rather a sceptic as to its effects, never having seen any person affected. I first breathed about six quarts of air, which proved to be only common atmospheric air, and which consequently produced no effect.

I then had six quarts of the oxide given me in a bag undiluted, and as soon as I had breathed three or four respirations, I felt myself affected and my respiration hurried, which effect increased rapidly until I became as it were entranced, when I threw the bag from me and kept breathing on furiously with an open mouth and holding my nose with my left hand, having no power to take it away though aware of the ridiculousness of my situation. Though apparently deprived of

* The doses in these experiments were from five to seven quarts.

all voluntary motion, I was sensible of all that passed, and heard every thing that was said; but the most singular sensation I had, I feel it impossible accurately to describe. It was as if all the muscles of the body were put into a violent vibratory motion; I had a very strong inclination to make odd antic motions with my hands and feet. When the first strong sensations went off, I felt as if I were lighter than the atmosphere, and as if I was going to mount to the top of the room. I had a metallic taste left in my mouth, which soon went off.

Before I breathed the air, I felt a good deal fatigued from a very long ride I had had the day before; but after breathing, I lost all sense of fatigue.

IX. *Detail of* MR. GEORGE BURNET.

I had never heard of the effects of the nitrous oxide, when I breathed six quarts of it. I felt a delicious tremour of nerve, which was rapidly propagated over the whole nervous system. As the action of inhaling proceeds, an irresistible *appetite* to repeat it is excited. There is now a general swell of sensations, vivid, strong, and inconceivably pleasurable. They still become more vigorous and glowing till they are communicated to the brain, when an ardent flush overspreads the face. At this moment the tube inserted in the air-bag was taken from my mouth, or I must have fainted in extacy.

The operation being over, the strength and turbulence of my sensations subsided. To this succeeded a state of feeling uncommonly serene and tranquil. Every nerve being gently agitated with a lively enjoyment, it was natural to expect that the effect of this

experiment would eventually prove debilitating. So far from this, I continued in a state of high excitement the remainder of the day after two o'clock, the time of the experiment, and experienced a flow of spirits not merely cheerful, but unusually joyous.

GEORGE BURNET.

X. *Detail of* MR. T. POPLÉ.

A disagreeable sensation as if breaking out into a profuse respiration, tension of the tympanum, cheeks and forehead; almost total loss of muscular power; afterwards increased powers both of body and mind, very vivid sensations and highly pleasurable. Those pleasant feelings were not new; they were felt, but in a less degree, in ascending some high mountains in Glamorganshire.

On taking it the second time, there was a disagreeable feeling about the face. In a few seconds, the feelings became pleasurable; all the faculties absorbed by the fine pleasing feelings of existence without consciousness; an involuntary burst of laughter.

THOMAS POPLÉ.

XI. *Detail of* MR. HAMMICK.

Having never heard any thing of the mode of operation of nitrous oxide, I breathed gas in a silk bag for some time, and found no effects, but oppression of respiration. Afterwards Mr. Davy told me that I had been breathing atmospheric air.

In a second experiment made without knowing what gas was in the bag, I had not breathed half a minute, when from the extreme pleasure I felt, I unconsciously

removed the bag from my mouth; but when Mr. Davy offered to take it from me, I refused to let him have it, and said eagerly, "let me breathe it again, it is highly pleasant! it is the strongest stimulant I ever felt!" I was cold when I began to respire, but had immediately a pleasant glow extending to my toes and fingers. I experienced from the air a pleasant taste which I can only call sweetly astringent; it continued for some time: the sense of exhilaration was lasting. This air Mr. Davy told me was nitrous oxide.

In another experiment, when I breathed a small dose of nitrous oxide, the effects were slight, and some time afterwards I felt an unusual yawning and languor.

The last time that I breathed the gas, the feelings were the most pleasurable I ever experienced; my head appeared light, there was a great warmth in the back, and a general unusual glow; the taste was distinguishable for some time as in the former experiment. My ideas were more vivid, and followed the natural order of association. I could not refrain from muscular action.

STEPHEN HAMMICK, Jun.

Sept. 15th.

XII. *Detail of* DR. BLAKE.

Dr. Blake inhaled about six quarts of the air, was affected during the process of respiring it with a slight degree of vertigo, which was almost immediately succeeded by a thrilling sensation extending even to the extremities, accompanied by a most happy state of mind and highly pleasurable ideas. He felt a great propensity to laugh, and his behaviour in some measure appeared ludicrous to those around him. Muscular

power seemed agreeably increased, the pulse acquired strength and firmness, but its frequency was somewhat diminished. He perceived rather an unpleasant taste in the mouth and about the fauces for some hours afterwards, but in every other respect, his feelings were comfortable during the remainder of the day.

TO MR. DAVY.

December 30th.

XIII. *Detail of MR. WANSEY.*

I breathed the gas out of a silk bag, believing it to be nitrous oxide, and was much surprised to find that it produced no sensations. After the experiment, Mr. Davy told me it was common air.

I then breathed a mixture of common air and nitrous oxide. I felt a kind of intoxication in the middle of the experiment, and stopping to express this, destroyed any farther effects.

I now breathed pure nitrous oxide; the effect was gradual, and I at first experienced fulness in the head, and afterwards sensations so delightful, that I can compare them to no others, except those which I felt (being a lover of music) about five years since in Westminster Abbey, in some of the grand chorusses in the Messiah, from the united powers of 700 instruments of music. I continued exhilarated throughout the day, slept at night remarkably sound, and experienced when I awoke in the morning, a recurrence of pleasing sensation.

In another experiment, the effect was still greater, the pulse was rendered fuller and quicker, I felt a sense of throbbing in the head with highly pleasurable thrillings all over the frame. The new feelings were at last so powerful as to absorb all perception. I distinguished

during and after the experiment, a taste on the tongue, like that produced by the contact of zinc and silver.

HENRY WANSEY.

XIV. *Detail of MR. RICKMAN.*

On inhaling about six quarts, the first altered feeling was a tingling in the elbows not unlike the effect of a slight electric shock. Soon afterwards, an involuntary and provoking dizziness as in drunkenness. Towards the close of the inhalation, this symptom decreased; though the nose was still involuntarily held fast after the air-bag was removed. The dose was probably an under-charge, as no extraordinary sensation was felt more than half a minute after the inhalation.

J. RICKMAN.

XV. *Detail of MR. LOVELL EDGORTH.*

My first sensation was an universal and considerable tremor. I then perceived some giddiness in my head, and a violent dizziness in my sight; those sensations by degrees subsided, and I felt a great propensity to bite through the wooden mouth-piece, or the tube of the bag through which I inspired the air. After I had breathed all the air that was in the bag, I eagerly wished for more. I then felt a strong propensity to laugh, and did burst into a violent fit of laughter, and capered about the room without having the power of restraining myself. By degrees these feelings subsided, except the tremor which lasted for an hour after I had breathed the air, and I felt a weakness in my knees. The principal feeling through the whole of the time, or what I should call the characteristical part of the effect, was a

total difficulty of restraining my feelings, both corporeal and mental, or in other words, not having any command of one's self.

XVI. *Detail of Mr. G. BEDFORD.*

I inhaled 6 quarts. Experienced a sensation of fullness in the extremities and in the face, with a desire and power of expansion of the lungs very pleasurable. Feelings similar to intoxication were produced, without being disagreeable. When the bag was taken away, an involuntary though agreeable laughter took place, and the extremities were warm.

In about a quarter of an hour after the above experiment, I inhaled 8 quarts. The warmth and fulness of the face and extremities were sooner produced during the inspiration. The candle and the persons about me, assumed the same appearances as took place during the effect produced by wine, and I could perceive no determinate outline. The desire and power to expand the lungs was increased beyond that in the former experiment, and the whole body and limbs seemed dilated without the sense of tension, it was as if the bulk was increased without any addition to the specific gravity of the body, which was highly pleasant. The provocation to laughter was not so great as in the former experiment, and when the bag was removed, the warmth almost suddenly gave place to a coldness of the extremities, particularly of the hands, which were the first to become warm during the inspiration. A slight sensation of fullness not amounting to pain in the head, continued for some minutes. After the first experiment, a sensa-

tion in the wrists and elbows took place, similar to that produced by the electric shock.

G. C. BEDFORD.

March 30th, 1800.

XVII. *Detail of Miss RYLAND.*

After having breathed five quarts of gas, I experienced for a short time a quickness and difficulty of breathing, which was succeeded by extreme languor, resembling fainting, without the very unpleasant sensation with which it is usually attended. It entirely deprived me of the power of speaking, but not of recollection, for I heard every thing that was said in the room during the time; and Mr. Davy's remark "that my pulse was very quick and full." When the languor began to subside, it was succeeded by restlessness, accompanied by involuntary muscular motions. I was warmer than usual, and very sleepy for several hours.

XVIII. *Letter from Mr. M. M. COATES.*

I will, as you request, endeavour to describe to you the effect produced on me last Sunday se'nnight, by the nitrous oxide, and will at the same time tell you what was the previous state of my mind on the subject.

When I sat down to breathe the gas, I believed that it owed much of its effect to the predisposing agency of the imagination, and had no expectation of its sensible influence on myself. Having ignorantly breathed a bag of common air without any effect, my doubts then arose to positive unbelief.

After a few inspirations of the nitrous oxide, I felt a fulness in my head, which increased with each inhala-

tion, until, experiencing symptoms which I thought indicated approaching fainting, I ceased to breathe it, and was then confirmed in my belief of its inability to produce in me any pleasurable sensation.

But after a few seconds, I felt an immoderate flow of spirits, and an irresistible propensity to violent laughter and dancing, which, being fully conscious of the violence of my feelings, and of their irrational exhibition, I made great but ineffectual efforts to restrain; this was my state for several minutes. During the rest of the day, I experienced a degree of hilarity altogether new to me. For six or seven days afterwards, I seemed to feel most exquisitely at every nerve, and was much indisposed to my sedentary pursuits; this acute sensibility has been gradually diminishing; but I still feel somewhat of the effects of this novel agent.

Yours truly,

M. M. COATES.

TO MR. DAVY.

June 11th, 1800.

DIVISION III.

ABSTRACTS FROM ADDITIONAL DETAILS.—OBSERVATIONS ON THE EFFECTS OF NITROUS OXIDE, BY DR. BEDDOES.—CONCLUSION.

I. *Abstracts from Additional Details.*

THE trials related in the following abstracts have been chiefly made since the publication of Dr. Beddoes's Notice. Many of the individuals breathed the gas from pure curiosity. Others with a disbelief of its powers.

Mr. Wynne, M.P. breathed five quarts of diluted

nitrous oxide, without any sensation. Six quarts produced fulness in the chest, heat in the hands and feet, and sense of tension in the fingers, slight but pleasant sensations. Seven quarts produced no new nor different effects.

Mr. Mackintosh several times breathed nitrous oxide. He had sense of fulness in the head, thrillings, tingling in the fingers, and generally pleasurable feelings.

Mr. John Cave, jun. from breathing four quarts of nitrous oxide, felt sensations as from superior wine, and general pleasant feelings.

Mr. Michael Castle, from five quarts, experienced sensations of heat and thrilling, general spirits heightened considerably as from wine; afterwards, slight pain in the back of the head.

Mr. H. Cardwell, from five quarts, had feelings so pleasurable as almost to destroy consciousness; almost convulsed with laughter; for a long time could not think of the feeling without laughing; sensation of lightness for some time after.

Mr. Jarman, from five quarts, great pleasure, laughter, certainly better spirits, glow in the cheeks which continued long.

The gentleman who furnished the preceding detail, had heard of the effects of nitrous oxide, and was prepared to experience new sensations: I therefore gave him a bag of common air which he respired, believing it to be nitrous oxide; and was much surprised that no effects were produced. He then breathed five quarts of nitrous oxide, and after the experiment, gave this account of his sensations.

Rev. W. A. Cane, after inhaling the gas, felt the most delicious sensations accompanied by a thrill through every part of his body. He did not think it possible so

charming an effect could have been produced. He had heard of the gas; but the result of the experiment far exceeded his expectations.

May 6th, 1800.

Mr. Joseph Priestley, from breathing nitrous oxide, generally had unpleasant fulness of the head and throbbing of the arteries, which prevented him from continuing the respiration.

Dr. Beddoes mentioned in his Notice, that Mr. Josiah Wedgwood and Mr. Thomas Wedgwood experienced rather unpleasant feelings from the gas. Mr. Josiah Wedgwood has since repeated the trial, the effects were powerful, but not in the slightest degree pleasant.

Mr. R. Boulton and Mr. G. Watt have been much less affected than any individuals.

Many other persons have respired the gas, but as their accounts contain nothing unnoticed in the details, it is useless to particularise them.

The cases of all the males who have been unpleasantly affected since we have learned to prepare the gas with accuracy, are related in this Section and in the last Division. Those who have been pleasantly affected after a fair trial and whose cases are not noticed, generally experienced fulness in the head, heat in the chest, pleasurable thrillings, and consequent exhilaration.

To persons who have been unaccustomed to breathe through a tube, we have usually given common air till they have learned to respire with accuracy: and in cases where the form of the mouth has prevented the lips from being accurately closed on the breathing tube, by the advice of Mr. Watt, we have used a tin plate conical mouth-piece fixed to the cheeks, and accurately adapted

to the lips; by means of which precautions, all our later trials have been perfectly conclusive.

II. *Of the Effects of Nitrous Oxide upon Persons inclined to Hysterical and Nervous Affections.*

The case of Miss — N. and other cases, detailed by Dr. Beddoes in his Notice, seemed to prove that the action of nitrous oxide was capable of producing hysterical and nervous affections in delicate and irritable constitutions.

On this subject, we have lately acquired additional facts.

Miss E. a young lady who had been subject to hysterical fits, breathed three quarts of nitrous oxide mingled with much common air, and felt no effects but a slight tendency to fainting. She then breathed four quarts of pure nitrous oxide: her first inspirations were deep, her last very feeble. At the end she dropt the bag from her lips, and continued for some moments motionless. Her pulse which at the beginning of the experiment was strong, appeared to me to be at this time, quicker and weaker. She soon began to move her hands and talked for some minutes incoherently, as if ignorant of what had passed. In less than a quarter of an hour, she had recovered, but could give no account of her sensations. A certain degree of languor continued through the day.

A young lady who never had hysterical attacks, wished to breathe the gas. I informed her of the disagreeable effects it had sometimes produced, and advised her, if she had the slightest tendency to nervous affection, not to make the trial. She persisted in her resolution.

To ascertain the influence of imagination, I first gave her a bag of common air, which she declared produced no effect. I then ordered for her a quart of nitrous oxide mingled with two quarts of common air; but from the mistake of the person who prepared it, three quarts of nitrous oxide were administered with one of common air. She breathed this for near a minute, and after the experiment, described her sensations as unpleasant, and said she felt at the moment as if she was dying. The unpleasant feelings quickly went off, and a few minutes after, she had apparently recovered her former state of mind. In the course of the day, however, a violent head-ache came on, and in the evening after she had taken a medicine which operated violently, hysterical affections were produced, followed by great debility. They occasionally returned for many days, and she continued weak and debilitated for a great length of time.

Mrs. S. a delicate lady, liable to nervous affections, who had heard of the cases just detailed, chose to breathe the gas. By three quarts she was thrown into a trance, which lasted for three or four minutes. On recovering, she could give no account of her feelings, and had some languor for half an hour afterwards.

These phenomena have rendered us cautious in administering the gas to delicate females. In a few instances, however, it has been taken by persons of this class, and even by those inclined to hysterical and nervous complaints with pleasurable effects.

Miss L. a young lady who had formerly had hysterical fits, breathed a quart of nitrous oxide with three quarts of common air without effect. Two quarts of nitrous oxide with one of common air produced a slight giddiness; four quarts of nitrous oxide produced a fit of

immoderate laughter, which was succeeded by slight exhilaration, her spirits were good throughout the day, and no depression followed.

Miss B. Y—— and Miss S. Y—— both delicate but healthy young ladies, were affected very pleasantly; each by three quarts of nitrous oxide, the first time of respiring it. Miss B. Y—— continued exhilarated and in high spirits for some hours after the dose. Miss S. Y—— had a slight head-ache, which did not go off for some hours.

Mrs. F. inclined to be hysterical, breathed four quarts of nitrous oxide mingled with common air. She was giddy, and described her feelings as odd; but had not the slightest languor after the experiment.

III. *Observations on the Effects of Nitrous Oxide, by* DR. BEDDOES.

Neither my notes nor my recollection supply much in addition to what I formerly stated in the *Notice of Observations at the Pneumatic Institution. Longman.* The gas maintains its first character as well in its effects on me, as in the benefit it confers on some of the paralytic, and the injury it does or threatens to the hysterical and the exquisitely sensible. I find that five or six quarts operate as powerfully as ever. I seem to make a given quantity go farther by holding my breath so that the gas may be absorbed in a great degree without returning into the bag, and therefore, be as little heated before inspiration as possible. This may be fancy.

After innumerable trials, I have never once felt lassitude or depression.* Most commonly I am sensible of

* Of the facts on which Brown founded his law of indirect debility, no prudent man will lose sight either in practising or studying medicine.

a grateful glow, *circum præcordia*. This has continued for hours. In two or three instances only has inhalation failed to be followed by pleasurable feeling; it has never been followed by the contrary. On a few occasions, before the gas was exhausted, I have found it impossible to continue breathing.

The pulse at first becomes fuller and stronger. Whenever, after exposure to a cold wind, the warmth of the room has created a glow in the cheeks, the gas has increased this to strong flushing—which common air, breathed in the same way, failed to do.

Several times I have found that a cut which had ceased to be painful has smarted afresh, and on taking two doses in succession, the smarting ceased in the interval, and returned during the second respiration. I had no previous expectation of the first smarting.

The only time I was near rendering myself insensible to present objects, by very carefully breathing several doses in quick succession, I forcibly exclaimed, TONES! In fact, besides a general thrilling, there seemed to be quick and strong alterations in the degree of illumi-

They are incontrovertible;—and our new facts may doubtless be conciliated to the Brunonian doctrine.

But to suppose that the expenditure of a quality or a substance or a spirit, and its renewal or accumulation are the general principles of animal phenomena, seems to me a grievous and baneful error. I believe it often happens that excitement and excitability increase, and that they oftener decrease together. In short, without generalizing in a manner, of which Brown and similar theorists had no conception, our notions of the living world will, in my opinion, continue to be as confused as the elements are said to have been in chaos. On some future occasion, I may presume to point out the region through which I imagine the path to wind, that will lead the observers of some distant generation to a point, whence they may enjoy a view of the subtle, busy and intricate movements of the organic creation as clear as Newton obtained of the movements of the heavenly masses.

nation of all surrounding objects; and I felt as if composed of finely vibrating strings. On this occasion, the skin seemed in a state of constriction, and the lips glued to the mouth-piece, and the mucous membrane of the lungs contracted, but not painfully. However, no constriction or corrugation of the skin could be seen. I am conscious of having made a great number of observations while breathing, which I could never recover.

Immediately afterwards I have often caught myself walking with a hurried step and busy in soliloquy. The condition of general sensation being as while hearing cheerful music, or after good news, or a moderate quantity of wine.

Mr. John Cave, Jun. and his three friends, as well as others, compared the effects to champagne. Most persons have had the idea of the effect of fermented liquors excited by the gas. It were to be wished that we had, for a standard of comparison, observations on the effect of these liquors, as diversified and as accurate as we have obtained concerning the gas; nor would more uniformity in the action of these substances be observed if the enquiry were strictly pursued. Opium and spirits seem, in particular states, to sicken and distress in the first instance; how differently does wine, at an early hour and fasting, act upon those who are accustomed to take it only after dinner!

I thought it might be an amusing spectacle to see the different tints of blood flowing from a wound by a leech in consequence of breathing different airs. The purple from the nitrous oxide was very evident. Oxygen, we thought, occasioned a quicker flow and brighter colour in the blood. In another experiment, an inflamed area round the puncture from a leech applied the day before, was judged by several spectators

to become much more crimson on the respiration of about 20 quarts of oxygen gas, which possibly acts more powerfully on inflamed parts.* These and many similar experiments, require to be repeated on the blood of single arteries opened in warm and cold animals.

It has appeared to me that I could hold my breath uncommonly long when respiring oxygen gas mixed with nitrous oxide. While trying this to-day, (17th June,) I thought the sense of smell much more acute after the nitrous oxide than before I began to respire at all; and then I felt conscious that this increased acuteness had before repeatedly occurred—a fact very capable, I apprehend, of a pneumatological interpretation.

Time by my feelings has always appeared longer than by a watch.

I thought of trying to observe whether while I alternately breathed quantities of nitrous oxide and oxygen gas and common air, I could observe any difference in the operation of a blister beginning to bite the skin. It would be of consequence to ascertain the effect of regulating by compression the flow of blood, while stimulants of various kinds (and heated bodies

* After writing this, I was present when an invalid, in whose foot the gout, after much wandering, had at last fixed, breathed 12 quarts of oxygen gas. While breathing, he eagerly pointed to the inflamed leg; and afterwards said he had felt in it a new sensation, somewhat like tension. I never had seen oxygen respired where there was so much local inflammation.

June 18. After 4 quarts of oxygen with 6 of nitrous oxide and then 6 of nitrous oxide alone, violent itching of the wounds made by the leech; and redness and tumour. Both had healed, and I did not expect to feel any thing more from them. I tried this again with two doses of nitrous oxide. The yellow halo round one wound changed to crimson, and there was so much stinging and swelling that I feared suppuration.—Absorption here was rapid.

among the rest) were applied to or near the extremities—because in erysipelas and various inflammatory affections, a ready and pleasant cure might be effected by partial compression of the arteries going to the diseased part; and a great improvement in practice thus obtained.

But I should run into an endless digression, were I to enumerate possible physiological experiments with artificial airs, or to speculate on the mechanical improvement of medicine, which at present, as far as mechanical means of affecting the living system are concerned, is with us in a state that would almost disgrace a nation of savages.

IV. *Conclusion.*

From the facts detailed in the preceding pages, it appears that the immediate effects of nitrous oxide upon the living system, are analogous to those of diffusible stimuli. Both increase the force of circulation, produce pleasurable feeling, alter the condition of the organs of sensation, and in their most extensive action destroy life.

In the mode of operation of nitrous oxide and diffusible stimuli, considerable differences, however, exist.

Diffusible stimuli act immediately on the muscular and nervous fibre. Nitrous oxide operates upon them only by producing peculiar changes in the composition of the blood.

Diffusible stimuli affect that part of the system most powerfully to which they are applied, and act on the whole only by means of its sympathy with that part. Nitrous oxide in combination with the blood, is universal in its application and action.

We know very little of the nature of excitement; as, however, life depends immediately on certain changes effected in the blood in respiration, and ultimately on the supply of certain nutritive matter by the lymphatics; it is reasonable to conclude, that during the action of stimulating substances, from the increased force of circulation, not only more oxygen and perhaps nitrogen must be combined with the blood in respiration,* but likewise more fluid nutritive matter supplied to it in circulation.

By this oxygen and nutritive matter excitability may be kept up: and exhaustion consequent to excitement only produced, in consequence of a deficiency of some of the nutritive principles, which are supplied by absorption.

When nitrous oxide is breathed, nitrogen (a principle under common circumstances chiefly carried into the blood by the absorbents in fluid compounds) is supplied in respiration; a greater quantity of oxygen is combined with the blood than in common respiration, whilst less carbonic acid and probably less water are evolved.

Hence a smaller quantity of nutritive matter is probably required from the absorbents during the excitement from nitrous oxide, than during the operation of stimu-

* See Dr. Beddoes's *Considerations*, part 1, page 26. His observations in the note in the last section will likewise apply here.—Is not healthy living action dependent upon a certain equilibrium between the principles supplied to the blood by the pulmonary veins from respiration and by the lymphatics from absorption? Does not sensibility more immediately depend upon respiration? Deprive an animal, under stimulation, of air, and it instantly dies; probably if absorption could be prevented, it would likewise speedily die. It would be curious to try whether intoxication from fermented liquors cannot be prevented by breathing, during their operation, an atmosphere deprived of part of its oxygen.

lants; and in consequence, exhaustion from the expenditure of nutritive matter more seldom occasioned.

Since Research III. has been printed, I have endeavoured to ascertain the quantities of nitrogen produced when nitrous oxide is respired for a considerable time. In one experiment, when I breathed about four quarts of gas in a glass bell over impregnated water for near a minute, it was diminished to about two quarts; and the residuum extinguished flame.

Now the experiments in Research II. prove that when nitrous oxide is decomposed by combustible bodies, the quantity of nitrogen evolved is rather greater in volume than the pre-existing nitrous oxide. Hence much of the nitrogen taken into the system during the respiration of nitrous oxide, must be either carried into new combinations, or given out by the capillary vessels through the skin.

It would be curious to ascertain whether the quantity of ammonia in the saline matters held in solution by the secreted fluids is increased after the respiration of nitrous oxide. Experiments made upon the consumption of nitrous oxide mingled with atmospheric air by the smaller animals, would go far to determine whether any nitrogen is given out through the skin.

The various effects of nitrous oxide upon different individuals and upon the same individuals at different times, prove that its powers are capable of being modified both by the peculiar condition of organs, and by the state of general feeling.

Reasoning from common phenomena of sensation, particularly those relating to heat, it is probable that pleasurable feeling is uniformly connected with a moderate increase of nervous action; and that this increase when carried to certain limits, produces mixed emotion

or sublime pleasure ; and beyond those limits occasions absolute pain.

Comparing the facts in the last division, it is likely that individuals possessed of high health and little sensibility, will generally be less pleasurable affected by nitrous oxide than such as have more sensibility, in whom the emotions will sometimes so far enter the limits of pain as to become sublime ;* whilst the nervous action in such as have exquisite sensibility, will be so much increased as often to produce disagreeable feeling.

Modification of the powers of nitrous oxide by mixture of the gas with oxygen or common air, will probably enable the most delicately sensible to respire it without danger, and even with pleasurable effects : heretofore it has been administered to such only in its pure form or mingled with small quantities of atmospheric air, and in its pure form even the most robust are unable to respire it with safety for more than five minutes.

The muscular actions † sometimes connected with the feelings produced by nitrous oxide, seem to depend in

* Sublime emotion with regard to natural objects, is generally produced by the connection of the pleasure of beauty with the passion of fear.

† The immortal Hartley has demonstrated that all our motions are originally automatic, and generally produced by the action of tangible things on the muscular fibre.

The common actions of adults may be distinguished into two kinds ; voluntary actions, and mixed automatic actions. The first are produced by ideas, or by ideas connected with passions. The second by impression, or by pleasure and pain.

In voluntary action, regular associations of ideas and muscular motions exist : as when a chemist performs a preconceived experiment.

In mixed automatic actions, the simple motions produced by impressions are connected with series of motions formerly voluntary, but now produced without the intervention of ideas : as when a person accus-

a great measure upon the particular habits of the individual ; they will usually be of that kind which is produced either by common pleasurable feelings or strong emotions.

Hysterical affection is occasioned by nitrous oxide, probably only in consequence of the strong emotion produced, which destroys the power of the will, and calls up series of automatic motions formerly connected with a variety of less powerful but similar feelings.

The quickness of the operation of nitrous oxide will probably render it useful in cases of extreme debility produced by deficiency of common exciting powers. Perhaps it may be advantageously applied mingled with oxygen or common air, to the recovery of persons apparently dead from suffocation by drowning or hanging.

The only diseases in which nitrous oxide has been hitherto employed, are those of deficient sensibility.—An account of its agency in paralytic affections will be speedily published by Dr. Beddoes.

As by its immediate operation the tone of the irritable fibre is increased, and as exhaustion rarely follows the violent muscular motions sometimes produced by it, it is not unreasonable to expect advantages from it in cases of simple muscular debility.

The apparent general transiency of its operation in the pure form in single doses has been considered as offering arguments against its power of producing lasting changes in the constitution. It will, however, be easy

tomed to play on the harpsichord, from accidentally striking a key, is induced to perform the series of motions which produce a well-remembered tune.

Evidently the muscular actions produced by nitrous oxide are mixed automatic motions.

to keep up excitement of different degrees of intensity for a great length of time, either by administering the unmingled gas in rapid successive doses, or by preserving a permanent atmosphere, containing different proportions of nitrous oxide and common air, by means of a breathing chamber.* That single doses, nevertheless, are capable of producing permanent effects in some constitutions, is evident, as well from the hysterical cases as from some of the details—particularly that of Mr. M. M. Coates.

As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place.

From the strong inclination of those who have been pleasantly affected by the gas to respire it again, it is evident that the pleasure produced is not lost, but that it mingles with the mass of feelings, and becomes intellectual pleasure, or hope. The desire of some individuals acquainted with the pleasures of nitrous oxide for the gas has been often so strong as to induce them to breathe with eagerness, the air remaining in the bags after the respiration of others.

As hydrocarbonate acts as a sedative,† and diminishes living action as rapidly as nitrous oxide increases it, on the common theory of excitability‡ it would follow, that by differently modifying the atmosphere by means of this gas and nitrous oxide, we should be in possession of a regular series of exciting and depressing§ powers

* See Res. IV. Div. I. page 288.

† Res. IV. Div. I. page 279.

‡ That of Brown modified by his disciples.

§ Supposing the increase or diminution of living action when produced by different agents, uniform, similar and differing only in degree ;

applicable to every deviation of the constitution from health: but the common theory of excitability is most probably founded on a false generalization. The modifications of diseased action may be infinite and specific in different organs; and hence out of the power of agents operating on the whole of the system.

Whenever we attempt to combine our scattered physiological facts, we are stopped by the want of numerous intermediate analogies; and so loosely connected or so independent of each other, are the different series of phenomena, that we are rarely able to make probable conjectures, much less certain predictions concerning the results of new experiments.

An immense mass of pneumatological, chemical, and medical information, must be collected, before we shall be able to operate with certainty, on the human constitution.

Pneumatic chemistry in its application to medicine, is an art in infancy, weak, almost useless, but apparently possessed of capabilities of improvement. To be rendered strong and mature, she must be nourished by facts, strengthened by exercise, and cautiously directed in the application of her powers by rational scepticism.

it would follow, that certain mixtures of hydrocarbonate and nitrous oxide, or hydrogen and nitrous oxide, ought to be capable of supporting the life of animals for a much longer time than pure nitrous oxide. From the experiments in Res. III. Div. I. it appears, however, that this is not the case.

It would seem, that in life, a variety of different corpuscular changes are capable of producing phenomena apparently similar; so that in the science of living action, we are incapable of reasoning concerning causes from effects.

APPENDIX.

APPENDIX, No. I.

EFFECTS OF NITROUS OXIDE ON VEGETATION.

IN July 1799, I introduced two small plants of spurge into nitrous oxide, in contact with a little water over mercury; after remaining in it two days, they preserved their healthy appearance, and I could not perceive that any gas had been absorbed. I was prevented by an accident, from keeping them longer in the gas.

A small plant of mint introduced into nitrous oxide and exposed to light, in three days became dark olive and spotted with brown; and in about six days was quite dead.—Another similar plant, kept in the dark in nitrous oxide, did not alter in colour for five days, and at the end of seven days, was only a little yellower than before. I could not ascertain whether any gas had been absorbed.

I introduced into nitrous oxide through water, a healthy budding rose, thinking that its colours might be rendered brighter by the gas. I was disappointed; it very speedily faded and died; possibly injured by the solution of nitrous oxide in water.

Of two rows of peas just appearing above ground, I watered one with solution of nitrous oxide in water, and the other with common water daily, for a fortnight. At the end of this time, I could perceive no difference in their growth, and afterwards they continued to grow equally fast.

I introduced through water into six phials, one of which contained hydrogen, one oxygen, one common air, one hydrocarbonate, one carbonic acid, and one nitrous oxide, six similar plants of mint, their roots being in contact with water, and their leaves exposed to light.

The plant in carbonic acid began to fade in less than two days, and in four was dead. That in hydrogen died in less than five days; that in nitrous oxide did not fade much for the first two days, but on the third, drooped very much, and was dead at the same time as that in hydrogen. The plant in oxygen for the first four days, looked flourishing and was certainly of a finer green than before; gradually, however, its leaves became spotted with black and dropped off one by one, till at the end of ten days they had all disappeared. At this time the plant in common air looked sickly and yellow, whilst that in hydrocarbonate was greener and more flourishing than ever.

I have detailed these experiments not on account of any important conclusions that may be drawn from them; but with a view of inducing others to repeat them, and to examine the changes effected in the gases. If it should be found by future experiments, that hydrocarbonate generally increased vegetation, it would throw some light upon the use of manures, containing putrefying animal and vegetable substances, from which this gas is perpetually evolved.

The chemistry of vegetation, though immediately connected with agriculture, the art on which we depend for subsistence, has been but little investigated. The discoveries of Priestley and Ingenhousz seem to prove that it is within the reach of our instruments of experiment.

APPENDIX, No. II.

APPROXIMATIONS TO THE COMPOSITION AND WEIGHT
OF THE AERIFORM COMBINATIONS OF NITROGEN.

AT TEMPERATURE 55°, AND ATMOSPHERIC PRESSURE 30.

Nitrogen	100 Cubic Inches	Grains		Nitrogen	Oxygen
With Oxygen	Nitrogen	30.04	100 grains are composed of		
	Oxygen	35.06			
	Atmospheric air	31.10		73.00	27.00
	Nitrous oxide	50.20		63.30	36.70
	Nitrous gas	34.26		44.05	55.95
	Nitric acid	76.00		29.50	70.50
With Hydrogen				Nitrogen	Hydrogen
	Ammonia	18.05		80.00	20.00

APPENDIX, No. III.

ADDITIONAL OBSERVATIONS.

a. In Res. I. Div. IV. sect. 3, in the analysis of nitrous gas by pyrophorus, as no absorption took place when the residual nitrogen was exposed to water, I inferred that if any carbonic acid was formed it was in quantity so minute, as to be unworthy of notice. A few days ago, I completely decomposed a quantity of nitrous gas by pyrophorus, when the residual nitrogen was exposed to solution of strontian, the fluid became slightly clouded; but no perceptible absorption took place.

b. If there was the least probability in any of Dr. Girtanner's speculations on the composition of Azote,* the experiments on the exhausted capacity† of the lungs in Res. III. might be supposed inconclusive. But there appears to be no more reason for supposing that hydrogen is converted into nitrogen by respiration, than for supposing that it is converted into water, carbonic acid or oxygen; for all these products are evolved when that gas is respired. From the comparison of Exp. 1 with

* *Annales de Chimie*, 100; and Mr. Tilloch's *Phil. Magazine*, 24.

† I regret much that I could not procure Dr. Menzies's *Observations on Respiration*, while I was making the experiments on the capacity of the lungs: they would probably have saved me some labour.

Exp. 3, Res. III. Div. II. sec. 4, it is almost demonstrated that no ascertainable change is effected in hydrogen by respiration. The experiment of the accurate Scheele, in which hydrogen after being respired thirty times in a bladder wholly lost its inflammability, may be easily accounted for from its mixture with the residual gases of the lungs.

About a fortnight ago, I respired, after forced voluntary exhaustion of my lungs, my nose being accurately closed, three quarts of hydrogen in a silk bag, at four intervals, for near five minutes. After this it was highly inflammable, and burnt with a greenish white flame in contact with the atmosphere; but was not so explosive as before.*

c. From what we have lately heard of the curious experiments of M. Volta and Mr. Carlisle, it is very probable that the conversion of nitrous gas into nitrous oxide when exposed to wetted zinc, copper and tin, in contact with mercury, as described in Res. I. Div. V. may in some measure depend on the action of the galvanic fluid. Whilst I was engaged in the experiments on this conversion, Dr. Beddoes† mentioned to me some curious facts noticed by Humboldt and Ritter, relating to the

* If loosely combined carbon exists in venous blood, hydrogen may probably dissolve a portion of it when respired and become slightly carbonated. At least there is as much probability in the supposition that carbon in loose affinity may combine with hydrogen at 98° as that it may combine with oxygen.

† Dr. Beddoes has since favoured me with the following account of these facts.

“M. Humboldt (ueber die gereizte Faser I. 473, 1797) quotes part of a letter from Dr. Ash, in which it is said that *if two finely polished plates of homogeneous zinc be moistened and laid together, little effect follows—but if zinc and silver be tried in the same way, the whole surface of the silver will be covered with oxidated zinc. Lead and quicksilver act as powerfully on each other, and so do iron and copper.*

oxidation of metals by the decomposition of water, which induced me to examine the phenomena with more attention than I should have otherwise done.—I recollect observing that some of the wetted zinc filings

—M. Humboldt (p. 474) says that, in repeating this experiment, he saw air-bubbles ascend, which he supposes to have been hydrogen gas from the decomposition of water. When he placed zinc simply on moist glass, the same phenomena took place, but more slowly and later. The quantity of oxide of zinc upon the glass alone was in 20 hours to that on the silver as one to three.

“In a very ingenious but obscurely written tract by Mr. Ritter, entitled *Evidence that the galvanic action exists in organic nature*, 8vo. Jena, 1800—The author observes, that the care of Dr. Ash and M. Humboldt that the metals should touch each other in as many points as possible was superfluous, even if we could grant that two metallic plates might be made by polishing, to touch in a number of points. To shew that it was sufficient if by touching in one point only they should form a complete galvanic circle, he dropped a single drop of distilled water upon the bust of a large silver coin. A piece of pure zinc was placed with its one end on the edge of the coin, while the other was supported by a bit of glass. The drop of water was neither in contact with the glass nor with the point at which the metals touched. The materials were left in this situation for four hours at the temperature of 68°. On taking them apart, the water had become quite milky and had half disappeared; and Mr. Ritter actually separated a quantity of white oxide that had been produced in the experiment.

“The pieces of metal were cleaned and laid together in the same manner, only that now a piece of paper was put between the metals at their former point of contact. In four hours first, and afterwards in ten, a faint ring of oxide only had been produced of which the quantity could not be estimated, nor could it be separated. In this case, the zinc had scarce lost anything of its splendour; in the former it had been corroded. In many repetitions of the experiment, he found that far more oxide was formed when the metals touched, than when they were separated to the slightest distance by an insulating body, even air.

“On exposing these apparatuses with somewhat more water to a considerable heat for four minutes, the water in the interrupted circle continued quite clear, while that in the other had become milk-white.

“The same phenomena were presented by other pairs of metals in a degree proportional to their galvanic activity; viz. by zinc and molybdæna, zinc and bismuth, zinc and copper, as also with tin and silver,

in nitrous gas on the side of the jar not in contact with the surface of mercury, were very slowly oxidated. Whilst on the surface of the mercury where small globules of that substance were mingled with the filings of zinc, the decomposition went on much more rapidly; possibly through the medium of the moisture, a series of galvanic circles were formed.

d. In Res. II. Div. I. it is stated, that nitrous oxide during its solution by common water, expels about $\frac{1}{6}$ of atmospheric air, the volume of the water being unity.

. From the delicate experiments of Dr. Pearson, on the passage of the electric spark through water, it appears however probable, that much more than $\frac{1}{6}$ of atmospheric air is sometimes held in solution by that fluid,*

tin and molybdæna, and lead and silver. The experiment with tin was particularly decisive, for when in contact with no other metal it was scarcely at all oxidated by water, though oxidation took place when tin was brought into contact with silver, and both were connected at the other end by a drop of water. What therefore took place in Dr. Ash's experiment, arose from an aggregation of galvanic circles of different forms.

"By the foregoing experiments, concludes Mr. Ritter, which though capable of the most various modifications, uniformly coincide in their main result, it is abundantly proved that *galvanic circles can be formed of merely inorganic bodies, by whose completion there is produced an action which ceases when the circle is opened.* The manner in which this has been shewn, proves also that *this action can effectuate sensible modifications in organic bodies*; and the process by which these modifications have been effected, made it evident that they *were not consequences of a momentary action of the circle, but of an action that is kept up while the circle remains entire*; for the process which brought this action under the cognizance of the senses went on, while the circle was unbroken, and its figure not brought back to that of a line.

"It is scarce necessary to observe that the experiments here quoted, are far from being the only ones on which the above conclusions rest."

T. B.

* Possibly a ratio exists between the solubility of gases in water, and the solubility of water in gases. It is probable from Mr. Wm. Henry's

possibly the whole of the air is not expelled by nitrous oxide, owing to some unknown law of saturation by which an equilibrium of affinity is produced, forming a triple compound.

curious experiments on the muriatic acid, that the absolute quantity of water in *many* gases, may be ascertained by means of its decomposition by the electric spark.

APPENDIX, No. IV.

DESCRIPTION OF A MERCURIAL AIR-HOLDER, SUGGESTED
BY AN INSPECTION OF MR. WATT'S MACHINE FOR CON-
TAINING FACTITIOUS AIRS.—BY WILLIAM CLAYFIELD.

SEVERAL modes of counteracting the pressure of a decreasing column of mercury having been thought of in conjunction with Mr. W. Cox, the following was at last adopted as the most simple and effectual.

Fig. 1. represents a section of the machine, which consists of a strong glass cylinder A, cemented to one of the same kind B, fitted to the solid block C, into which the glass tube D is cemented for conveying air into the moveable receiver E.

The brass axis F, fig. 2. having a double bearing at *a a*, is terminated at one end by the wheel G, the circumference of which is equal to the depth of the receiver, so that it may be drawn to the surface of the mercury by the cord *b* in one revolution; to the other end is fitted the wheel H, over which the balance cord *c* runs in an opposite direction in the spiral groove *e*, a front view of the wheel H is shewn at fig. 3.

Having loaded the receiver with the weight, I, something heavier than may be necessary to force it through the mercury, it is balanced by the small weight K, which hangs from that part of the spiral where the radius is equal to that of the wheel G; from this point the radius of the spiral must be increased in such pro-

portion, that in every part of its circuit, the weight K may be an exact counterpoise to the air-holder. In this way, so little friction will be produced, that merely plunging the lower orifice of the tube D under mercury contained in the small vessel L, will be sufficient to overcome every resistance, and to force the gas discharged from the beak of a retort into the receiver, where whatever may be its quantity, it will be subjected to a pressure exactly corresponding to that of the atmosphere. The edge of the wheel H being graduated, the balance cord *c* may be made to indicate its volume.

Should it at any time be necessary to reduce the pressure to the medium standard of the barometer, it may easily be done by graduating the lower end of the tube D, and adding to the weights I or K, as may be found necessary; the surface of the mercury in the tube pointing out the increase or diminution.

The concavity at the top of the internal cylinder is intended to contain any liquid it may be thought proper to expose to the action of the gas.

The upper orifice *f*, with its ground-stopper, is particularly useful in conveying air from the retort *g*, with its curved neck, into the receiver, without its passing through the tube D. In all cases where a rapid extrication of gas is expected, the retort *g*, should be firmly luted to the orifice, and the weight I, removed from the top of the receiver; this by diminishing the pressure, will admit the gas to expand freely in the air-holder at the instant of its formation, and prevent an explosion of the vessels. The same caution must be observed whenever any inflammation of gas is produced by the electric spark.

The air may be readily transferred through water or even mercury by the tube *h*, Fig. 1.

To prevent an absorption of mercury in case of a condensation taking place in the retort made use of for generating air, Mr. Davy has applied the stop-cock *i*, to which the neck is firmly luted. This stop-cock is likewise of great service in saturating water with acid or alkaline gases, which may be effected by luting one end of the tube *k* to the stop-cock, and plunging the other into the fluid in the small vessel *l*, cemented at top, and terminating in the bent funnel *m*,—the tube *h* having been previously removed, and the lower orifice of the tube *D* either sunk to a considerable depth in mercury, or closed with a ground stopper. The bend of the funnel *m*, may be accurately closed by the introduction of a few lines of mercury.

The application of the stop-cock *n*, has enabled Mr. Davy to perform some experiments on respiration with considerable accuracy.

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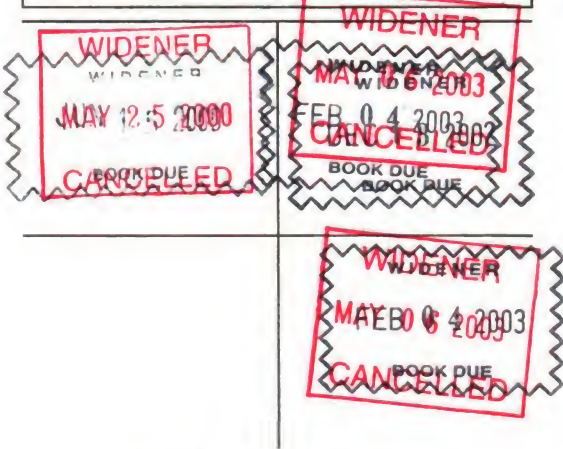


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